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OBITUARY.

Henry Woodward.

BORN 24TH NOVEMBER, 1832. DIED 6TH SEPTEMBER, 1921.

HENRY WOODWARD was born at Norwich on 24th November, 1832, the youngest son of Samuel Woodward, the well-known geologist and antiquary. His father died when he was 6 years old, and his early life was spent under difficult circumstances. He was educated at the Norwich Grammar School until the age of 14, when he left to accompany his brother, Samuel Pickworth Woodward, to Cirencester, where the latter was beginning his career as Professor of Natural History in the Royal Agricultural College. Henry Woodward was by inclination a naturalist from the beginning, and at Cirencester he had the opportunity of making systematic studies. In 1848 he removed to London with his brother, who was then appointed assistant in the Geological Department of the British Museum. Here he attempted to obtain congenial occupation, which would at the same time maintain him, but in 1851 he felt obliged to return to Norwich, where he spent seven years as a clerk in Gurney's Bank. At last, in 1858, he realized his ambition, and became an assistant in the Geological Department of the British Museum, of which he was eventually Keeper from 1880 until 1901.

As an officer of the British Museum, Henry Woodward devoted himself most assiduously to curatorial work, and when the collection of fossils was removed to South Kensington at the beginning of his Keepership, he planned and supervised the whole of the rearrangement in the new building. He made the public galleries more attractive by adding illustrative diagrams and descriptive labels, and he improved the guide-books by providing them with figures of important specimens. He also increased the value of the collections for the progress of science by planning and editing a series of catalogues, among which may be specially mentioned Etheridge and Carpenter's *Blastoidea*, Hinde's *Fossil Sponges*, Smith Woodward's *Fossil Fishes*, and Lydekker's *Fossil Reptiles, Birds, and Mammals*. His genial personality and helpful ways attracted an increasing number of scientific visitors, and as a result of his efforts the extent and scope of the collections enlarged with greater rapidity than at any previous time. He acquired not only

an immense mass of material for research, but also numerous particularly fine specimens which would be instructive for the public exhibition. Among the more important acquisitions were Williamson's Carboniferous Plants, Davidson's Brachiopods, Nicholson's Stromatoporoids, Stürtz's Devonian Starfishes, Egerton and Enniskillen's Fishes, Lewis' Lebanon Fishes, Leeds' Oxfordian Reptiles, and Forsyth Major's Pliocene Mammals from Samos.

In 1864 Henry Woodward joined Professor T. Rupert Jones in founding the GEOLOGICAL MAGAZINE, and from July, 1865, until the end of 1918 he was sole editor. It is unnecessary to refer to the influence of this serial on the progress of research—it is sufficient to repeat the common saying that almost every British recruit to geology since 1864 has begun authorship in its pages. Under Woodward's judicious and tactful editorial direction, it always welcomed and published honest work, whether on orthodox lines or otherwise; and it afforded a medium for discussion not to be found elsewhere. If his well-laid plans and methods are followed, the MAGAZINE cannot fail to continue its usefulness—provided, of course, that the new generation is willing to give it the same financial support as its predecessors.

Soon after he joined the staff of the British Museum, Henry Woodward began to write notes on newly acquired fossils, which were of general interest. Among these his account of the primitive Jurassic bird, *Archaeopteryx*, in the *Intellectual Observer* for 1862, must be specially mentioned. After the foundation of the GEOLOGICAL MAGAZINE, most of his notes were contributed to its pages, and one of these, in the first volume, on the skull of a mammoth found at Ilford, is particularly memorable. In this communication the first well-preserved skull of an English mammoth is noticed, and as soon as the specimen was mounted in 1868 he pointed out the true inward curvature of the tusks, which showed that in the published figures of the Siberian mammoth in Petrograd the tusks were reversed. In 1869 he wrote on the peaty deposits in the Lea valley, in which numerous Holocene mammalian remains had just been found. In this, and in a later paper, published by the Essex Field Club in 1882, he emphasized the geological importance of the work of beavers, both in the Lea valley and in the Fenland. In 1871, in a paper read before the Geological Society, he discussed the fossil links between birds and reptiles, and referred to the footprints of bipedal reptiles in the lithographic stone of Solenhofen, Bavaria. In 1885, to the same Society, he gave an account of a skeleton of the gigantic extinct Sirenian, *Rhytina*, which had recently been acquired by the British Museum.

Henry Woodward's chief contributions to science, however, were his descriptive memoirs and papers on fossil Crustacea and other Arthropods, on which he became a leading authority. The first of his long series of original papers, on a new macrurous Crustacean from the Lower Lias of Lyme Regis, was published by the Geological

Society in 1863. From 1865 to 1875 he contributed an annual report on British fossil Crustacea to the British Association, and made many advances in knowledge of the subject. In 1864 he exhibited to the British Association at Bath some restorations of the strange Devonian Merostomata, and for many years devoted special attention to this group, which he described in a monograph issued by the Palæontographical Society 1866–78. He pointed out the relationship of the Eurypterids to the existing Xiphosura (king crabs) more clearly than it had been done previously. He also contemplated continuing Salter's unfinished work on the British Trilobites, but unfortunately completed only one small volume on the Carboniferous genera (Palæontographical Society, 1883–4). He joined Professor Rupert Jones in a monograph of the British Palæozoic Phyllopoda (Phyllocarida), likewise published by the Palæontographical Society in 1888. Early in his career he prepared a useful Chart of Fossil Crustacea, with the aid of Mr. J. W. Salter; and in 1877 he summarized all that was known of British Fossil Crustacea in a British Museum Catalogue. During more recent years he also published much on the Carboniferous Arachnids, Myriapods, and Insects, especially from the English Coal Measures. All his papers were well illustrated, many by his daughters.

Henry Woodward occasionally described other invertebrate fossils besides Arthropods, and among his contributions to the Geological Magazine are accounts of Tertiary shells from Sumatra (1879), Palæozoic fossils from Beechey Island (1878), and a well-preserved cuttle-fish from the Chalk of Mount Lebanon (1883).

Almost all Henry Woodward's writings may be described as bringing together useful materials for science rather than as finished contributions. He rarely did more than state the facts and make a few obvious comparisons. He always hesitated to deal with principles, and although he admitted the general truth of the doctrine of evolution, he left to others its application to palæontological research. At the same time he encouraged younger students to adopt the new methods, and he was ever eager to help them with his learning and judicious criticism. He realized the possibility of formulating at least some laws; he only insisted on tempering scientific enthusiasm with discretion.

In 1857 Henry Woodward married Miss Ellen Sophia Page, of Norwich, who took a keen interest in his work, and gave him much help until her death in 1913. Readers of the Geological Magazine remember with gratitude her valuable index to the first forty volumes, which was published in 1905. Of the two sons, both already dead, Harry P. Woodward was for several years Government Geologist of West Australia, while Martin F. Woodward began a promising career as a zoologist. Of the five daughters, Miss Gertrude M. Woodward has long been known for her beautiful illustrations of fossils and zoological specimens in the works of many authors.

Henry Woodward took a very active share in the work of the Geological Society. He was elected a Fellow in 1864, was awarded

the Wollaston Fund in 1866, the Lyell Fund in 1879, the Murchison Medal in 1884, became President in 1894, and received the Wollaston Medal in 1906. He was also an early member of the Geologists' Association, became President in 1873, and from 1875 onwards was an honorary member. He joined the Palæontographical Society at the beginning of his career, and in 1895 he succeeded Professor Huxley as President, retaining this office until his death. He was President of Section C of the British Association at Manchester in 1887. He was the first President of the Malacological Society in 1893, and he served two years as President of the Royal Microscopical Society in 1903–4. For many years he was also an active Vice-President of the Zoological Society. He was elected a Fellow of the Royal Society in 1873, and received the honorary degree of LL.D. from St. Andrews in 1878. He was an honorary member of many other Societies at home and abroad. In all his activities he was a cheery colleague, tactful and sympathetic and full of resource, and his loss is mourned by a large circle of devoted friends.

ORIGINAL ARTICLES.

The Magnesian Group of Igneous Rocks[1]

By F. Dixey, M.Sc., F.G.S., Government Geologist of Sierra Leone.

1. Introduction.
2. Description of the Magnesian Group.
3. The Magnesian Provinces.
4. Age of the Magnesian Group.
5. Origin of the Magnesian Group.
6. Relation to well-known Suites and Series.

I. Introduction.

ROCKS rich in magnesium are abundantly developed in a certain few areas of the world, whereas they are rare or absent in the remaining areas. With reference to the abundance of magnesian rocks in Southern India, for example, Holland has stated[2] :—

> The most remarkable feature which has been revealed by the recent microscopic study of the crystalline rocks in Southern India is the very great predominance of the pyroxenes (and especially of the rhombic forms of that group) amongst the ferro-magnesian silicates. In addition to the series described in this paper [Charnockite Series], which is probably the most abundant of all the rock groups in the southern portion of Peninsular India, and in every variety of which hypersthene is a constant and characteristic constituent, the central and eastern parts of the Madras Presidency are cut through by an enormous number of basic dykes, in which rhombic pyroxene is also a leading mineral. Judging thus by the mineralogical composition of the rocks, which is confirmed by the few chemical analyses that have so far been made, the bases magnesia and ferrous oxide must take an unusually prominent place amongst the chemical constituents of the southern portion of the Peninsula. Besides occurring as a constituent of the enstatites, which are so widely distributed through the Madras rocks, magnesia appears in even larger proportions in the peridotites, which, either as dunites, saxonites, picrites, or their decomposed forms magnesite, serpentine, and steatite, are now known to be far more abundant than was suspected at the time of the first recognition of these highly magnesian ultra-basic rocks near Salem in 1892.

Again, Lacroix has given a description of two series of analogous igneous rocks in West Africa; the first of these, the gabbro-peridotite series of French Guinea,[3] to which probably belongs the enormous noritic intrusion of the Sierra Leone Peninsula,[4] is characterized throughout by abundance of magnesian minerals, while the second,[5] a series comparable with the Charnockite Series of

[1] Paper read before Section C (Geology) of the British Association for the Advancement of Science, Edinburgh Meeting, September, 1921.

[2] "Charnockite Series of Igneous Rocks": *Mem. Geol. Surv. India*, vol. xxviii, 1900, p. 192.

[3] M. A. Lacroix, "Les Syénites Nephelinique de l'Archipel de Los": *Nouv. Arch. du Mus. d'Hist. Nat., Paris*, 5ème Serie, Tome 3, 1911, p. 108.

[4] F. Dixey, "The Norite of Sierra Leone": *Abs. Proc. Geol. Soc.*, 1921, p. 103.

[5] M. A. Lacroix, "Sur l'Existence à la Côte d'Ivoire d'une Série Petrographique comparable à celle de la Charnockite": *Comptes Rendus Hebdom. des Séances de l'Acad. des Sci.*, 150, 1910, p. 18.

India, although characterized in all members by hypersthene, is especially rich in this and other magnesian minerals in the less acid members. Recent work of the Geological Survey of Sierra Leone [1] has shown that these two series of rocks, in addition to huge masses of talc-schist, amphibolite, etc., are well represented in Sierra Leone also.

Thus it is seen that Southern India is largely composed of enormous masses of rocks belonging to the Charnockite Series, of associated peridotites and their altered equivalents, and of later noritic and pyroxenic dykes, and also that the older igneous rocks of at least the central and western parts of West Africa consist of a similar assemblage; these two areas may be considered as exhibiting typical developments of the group of igneous rocks now under consideration. A number of analogous areas will be cited in a later paragraph.

II. Description of the Magnesian Group.

Since the principal characteristic of these rocks is their richness in magnesium, it is proposed to distinguish them as a Magnesian Group of igneous rocks.[2] The term "group" is used in preference to "series" because, as will be shown below, the rocks in question include some or all of the members of certain series already recognized, and also because it is at present uncertain how far they form a continuous series in themselves. The rocks of this group give rise in various parts of the world to a limited number of Magnesian Provinces, of which West Africa may be taken as a good example, as indicated in the preceding paragraph. The term "Province" is here used essentially in a geographical sense, although, as will be seen below, the principal members of the group are of Archæan or very early age; moreover although the rocks of any one of the provinces do not necessarily belong to one igneous epoch, they are, nevertheless, related in important mineralogical and chemical characters.

It is, of course, recognized that highly magnesian rocks have occurred in all ages as differentiates of large intrusions of less basic composition; in the present paper, however, consideration is given essentially to the large magnesian intrusions, such as those of India referred to above, that apparently possess a separate existence. In all probability differentiation of some kind operated even in the production of these large intrusions, but this differentiation took place on a very large scale indeed, giving rise to the great crustal "shells" referred to below.

[1] F. Dixey, *Reps. Geol. Surv., Sierra Leone*, 1919–20.

[2] *Note.*—An analogous arrangement has been suggested by Washington with regard to a small group of rocks, characterized by high content of titanium, which he proposes to distinguish as a "Titanium Province". See H. S. Washington, "The Titaniferous Basalts of the Western Mediterranean": *Q.J.G.S.*, vol. lxiii, 1907, p. 69.

The distinguishing features of the Magnesian Group may be summarized as follows :—

Texturally, these rocks are often granular, and they are generally well-banded.

Chemically, the rocks are rich in magnesium and in iron, especially in the less siliceous varieties ; the abundance of these two constituents, combined with fairly low alumina and lime, leads to the persistence of hypersthene. There is wide variation in the content of silica.

Mineralogically, the rocks are almost invariably characterized by the presence of hypersthene, and a monoclinic magnesia-pyroxene sometimes accompanies and may even replace the hypersthene ; moreover, common augite is generally an important constituent. Olivine is often abundant in the more basic members of the group. Garnet is a common and sometimes abundant constituent, particularly amongst the older rocks.

Concerning the presence of garnets in the Charnockite Series of India, an important member of the Magnesian Group, Holland has stated [1] :—

> The prevalence of garnets in some members of the Charnockite Series which show no signs of dynamo-metamorphism, suggests that although pyroxene is the stable form of the same compound at low temperatures, there is an intermediate but high temperature, short of fusion, at which either hornblende or pyroxene breaks up into a more basic garnet and a more siliceous bye-product, quartz or felspar. It is to such a cause that the prevalence of garnets in these old pyroxenic rocks should be ascribed.[2]

Stillwell,[3] however, regards the peculiar mineralogical features of the Charnockite Series as due to recrystallization in the kata zone of metamorphism (Grubenmann) ; he considers that not only the garnet, but even the hypersthene, was produced in these circumstances. This does not accord with the obvious and almost unmodified igneous character of many of the rocks, and the present writer considers that the hypersthene at least is essentially a normal product of crystallization from the magmas, and that at least much of the garnet arose in this way. Garnet is now well-known to be a product of crystallization of many igneous rocks,[4] and Stillwell himself describes,[5] from certain rocks in Adelie Land closely analogous to the Charnockite Series, the case of a garnet mass which occurs graphically intergrown with quartz in pegmatite cutting a granodiorite gneiss free from garnets.

[1] Op. cit., p. 196. See also Fermor below, p. 490.

[2] See also Fermor on the ancient garnetiferous rocks of India, below, p. 490.

[3] "Metamorphic Rocks of Adelie Land" : *Rep. Aust. Ant. Exped.*, vol. iii, 1918, pt. i, p. 13. See also below, p. 489.

[4] In this connection it may be noted that Dr. J. W. Evans has recently postulated the formation of garnets, together with certain other minerals of small molecular volumes, in magmas crystallizing under conditions of high pressures and comparatively low temperatures. "The Origin of the Alkali Igneous Rocks" : GEOL. MAG., Vol. LVII, 1920, p. 559. See also note below, p. 491, on garnets and "piezocrystallization".

[5] Op. cit., p. 197.

Finally, it should be noticed that effusive rocks corresponding to the older and more important members of the group, such as the Charnockite Series and associated rocks, are not known, and also that the rocks of most of the magnesian provinces have been invaded by intrusions of very different composition, namely nepheline-syenites and associated rocks belonging to the Alkaline Series; as examples of these last may be given the nepheline-syenites of the Los Islands (West Africa),[1] the nepheline-syenites of India,[2] and the alkaline rocks of Scandinavia.[3]

The present writer recognizes that the Magnesian Group of rocks is not sharply divided from the rocks relatively poor in magnesium, any more than the alkaline, calc-alkaline, spilitic, and other petrographic suites are sharply divided from each other; most of these suites, in fact, either overlap or are indistinguishable at their acid and basic ends respectively, and it is, moreover, not always possible to distinguish between their intermediate members. Nevertheless, the conception of these suites has so far served a very useful purpose in petrography.

III. The Magnesian Provinces.

Reference has already been made to two examples of Magnesian Provinces, but there is reason to believe that similar Provinces exist also in the ten additional areas listed below; the rocks of the Group, however, appear to be developed to a variable extent in the different Provinces, and subsequent investigation may necessitate modification or extension of the list.

1. Ekersund, Soggendal, and Bergen districts in western and south-western Norway.[4]
2. Saxony and neighbouring areas, from which "pyroxene-granulites" and "pyroxene-gneisses" have frequently been described by earlier writers.[5]
3. Ural Mountains.[6] (The rocks of this area, although resembling those of the other areas in many respects, generally carry augite instead of hypersthene.)
4. Southern India.[7]
5. West Africa.[8]
6. Eastern part of Ellesmere Land and Prudhoe Land.[9]

[1] Lacroix, op. cit., 1911.

[2] *Mem. Geol. Surv. India*, vol. xxx, 1900, pt. ii.

[3] Daly has commented upon the association of anorthositic and syenitic types both in the Adirondacks and in Western Norway. See *Igneous Rocks and their Origin*, 1914, p. 54.

[4] C. F. Kolderup, *Berg. Mus. Aarb.*, 1896, No. V; also 1903, No. 12.

[5] Rosenbusch, *Elemente der Gesteinslehre*, 1910, p. 187.

[6] See H. S. Washington, "The Charnockite Series of Igneous Rocks": *Amer. Journ. Sci.*, 1916, p. 323. Also J. P. Iddings, *Igneous Rocks*, vol. ii, 1913, p. 511.

[7] *Memoirs Geol. Surv. India.*

[8] See above, p. 486.

[9] C. Bugge, *Rep. 2nd Fram Exped.*, No. 22, 1910.

7. Haliburton and Bancroft Areas, Canada.[1]
8. The Cortlandt Area, New York.[2]
9. The Blue Ridge, Virginia.[3]
10. State of Bahia, Brazil.[4]
11. Southern Eyre Peninsula, Australia.[5]
12. Adelie Land, Antarctica.[6]

It may be mentioned at this point that the North-West Highlands of Scotland,[7] although lacking in typical development of the rocks of the Magnesian Group, is nevertheless related to many of the above areas in several important respects, particularly in the prevalence of amphibolites of various kinds.

IV. Age of the Magnesian Group.

It will at once be noticed that the areas given in the preceding paragraph include the more important known outcrops of pre-Cambrian igneous and metamorphic rocks, and attention may here be drawn to the remarkable lithological similarity of the pre-Cambrian terranes, a similarity which has already been noticed by several writers. Thus it may reasonably be concluded, in spite of the abundance of pre-Cambrian granitic rocks, that rocks of the Magnesian Group were of much greater importance in pre-Cambrian than in later times. This conclusion receives support from Daly's investigation into the relative abundance of and the time relations of the different families of igneous rocks;[8] and from his table[9] of the order of eruption of igneous rocks in different parts of the world it is obvious that rocks relatively rich in magnesium were intruded more frequently and bulked more largely in pre-Cambrian than in later periods.

V. Origin of the Magnesian Group.

Whatever cosmic hypothesis be adopted there is good reason to suppose that at a very early stage in the earth's geological history what is now known as the "crust" underwent a certain amount of differentiation leading to a density stratification. Moreover, in view of this early differentiation, the crust may be regarded[10] as consisting

[1] J. P. Iddings, *Igneous Rocks*, vol. ii, 1913, p. 358.
[2] G. S. Rogers, *Ann. N. Y. Ac. Sci.*, xxi, 1911, p. 11.
[3] Watson, *Bull. Geol. Soc. Amer.*, 1915.
[4] See H. S. Washington, op. cit. supra.
[5] C. E. Tilley, "The Granite-Gneisses of Southern Eyre Peninsula (South Australia) and their Associated Amphibolites": *Q.J.G.S.*, vol. lxxvii, 1921, p. 75.
[6] F. L. Stillwell, "The Metamorphic Rocks of Adelie Land": *Rep. Aust. Ant. Exped.*, vol. iii, pt. i, 1918.
[7] "The North-Western Highlands of Scotland": *Mem. Geol. Surv. Great Britain*, 1907.
[8] *Igneous Rocks and their Origin*, 1914, p. 55.
[9] Op. cit., p. 469.
[10] See Daly, *Igneous Rocks and their Origin*, 1914, p. 171.

of the following three shells which underlie, in downward succession, a discontinuous sedimentary shell :—

1. Granitic shell.
2. Transitional shell.
3. Basaltic shell.

Finally, as has been suggested by several authors [1] from consideration of the composition of meteorites, it is highly probable that the basaltic shell is underlain by a peridotic shell. If any such view be accepted, the known restriction of the majority of the magnesian rocks to the older parts of the earth's crust and to very early times receives some explanation ; in the first place, the deep-seated, highly magnesian magma of the lowest shell would be less likely to reach the higher parts of the crust than the overlying less magnesian rocks ; secondly, in the course of time these eruptions would get less and less chance of reaching higher levels, both because the solid crust would probably be increasing in thickness and because, with continued density stratification, the magnesian magmas would become more and more inaccessible ; and thirdly, the rocks once situated at a great depth would now be exposed at the surface only in those areas, such as Southern India [2] for example, in which uplift and progressive denudation have proceeded more or less uninterruptedly over a very long period of time. These ancient magnesian intrusives were frequently of very great size, and in this connection Holland has observed [3] : " There is a strong probability that the magmas tapped in earlier geological periods were larger than those which gave rise to eruptions after the earth's crust had advanced in physical differentiation." The great variation in acidity shown by some members of the Magnesian Group may be explained by intermixture of the magnesian magma with varying amounts of the overlying magmas. That this intermixture would often be considerable may be assumed from the extraordinary development of igneous activity of all kinds in earlier periods of the earth's history.

Fermor,[4] in an attempt to explain the common occurrence of garnet in the ancient rocks of India, and noting that the formation of this mineral in a rock is accompanied by a reduction in volume, came to the conclusion that the garnetiferous rocks originate in a relatively basic " infra-plutonic zone " of great depth and unusually high pressure.[5] He states,[6] moreover :—

[1] Daly, op. cit. Also L. L. Fermor, *Rec. Geol. Surv. India*, vol. xliii, 1913, p. 41.

[2] T. H. Holland, " The Charnockite Series " : *Mem. Geol. Surv. India*, xxviii, 1900, p. 196.

[3] Op. cit.

[4] " Preliminary Note on Garnet as a Geological Barometer and on an Infra-plutonic Zone in the Earth's Crust " : *Rec. Geol. Surv. India*, vol. xliii, 1913, p. 41.

[5] Cf. also Dr. J. W. Evans ; see footnote on p. 487 above.

[6] Id., p. 44.

> A release of pressure over any given portion of the infra-plutonic shell would allow the liquefaction of that portion of the shell under the high temperatures prevalent; such liquid rock, on being intruded into the higher portions of the earth's crust, would then solidify under less pressure as a plutonic rock. But in these circumstances, doubtless comparatively rare, in which the isogeotherms are lowered more rapidly than the pressure, it can easily be imagined that the rock would be able to crystallize in its infra-plutonic form, and then, by subsequent earth movements and denudation, be exposed at the surface.[1]

Stillwell, however, in opposition to this view, states [2] that "the 'infra-plutonic zone' is indistinguishable from a metamorphic zone defined by the particular set of conditions", and he endeavours to show, moreover, that the garnets, the granularity,[3] and, in fact, all the peculiar features of these rocks, are due to recrystallization in the solid state. In extension of this idea, he even argues [4] that the following hypotheses, "founded on the transition between two rock types in metamorphic areas", might be explained "on the hypothesis of metamorphic diffusion", which he also regards as operating in the solid state:—

1. Intermingling of basic magmas with acid magma.
2. Differentiation of an intermediate magma into a relatively basic portion and a relatively acid portion.
3. Local melting or refusion in situ.
4. Gradual assimilation of pre-existing basic sediments by invading granite or gneiss.

It would indeed be strange if these ancient rocks had not suffered some metamorphism at least, but the evidence brought forward to show that metamorphic diffusion in the solid state is capable of producing such remarkable changes in the character of the rocks is far from being convincing.

Dr. J. W. Evans considers the presence of abundant hypersthene in charnockitic rocks as due to the influence of excess alumina, which he regards as having been derived by the absorption of aluminous sediments.[5] So far there does not appear to be very much direct evidence in support of this theory in the various areas considered in this paper; in one of these areas, at least, namely the

[1] See also Holland on garnets in ancient rocks of Southern India, above, p. 485. Moreover, E. Weinschenk has brought forward evidence to show that the garnets, as well as the granularity, of the central granitic gneisses of the Alps may be regarded as having been produced during the crystallization of a viscous magma under the operation of a powerful directed pressure ("piezocrystallization"), and not by later metamorphism. *Cong. Géol. Inter., C.R.*, viii, 1900, p. 326.

[2] Op. cit. supra, p. 196.

[3] Granularity cannot necessarily be regarded as evidence of metamorphism; many igneous rocks are known to possess well-developed granular texture as a result of disturbance of some kind during crystallization. See Weinschenk *re* "piezocrystallization", op. cit. supra, and also F. Dixey, "The Norite of Sierra Leone": *Proc. Geol. Soc.*, 1921, p. 103.

[4] Op. cit., p. 121.

[5] *Abs. Proc. Geol. Soc.*, 1921, p. 46.

Southern Eyre Peninsula, the theory has been held to be inapplicable.[1]

VI. Relation of the Magnesian Group of Igneous Rocks to the Alkaline, Calc-Alkaline, and other Series of Rocks.

A number of petrographic suites and series are already more or less well-known, and an attempt will be made in the following paragraphs to show what relation they bear to the Magnesian Group of rocks.

The series of rocks which most closely approaches the Magnesian Group is the Charnockite-Anorthosite Series proposed by Rosenbusch;[2] this series is said to contain many intermediate stages between the acid charnockite and the basic anorthosite, and also to possess peridotic and pyroxenic end-members. It should be noted, however, that many anorthosite masses contain only a small proportion of rocks rich in magnesium. The series is much more frequently found in association with the Calc-Alkaline Series than with the Alkaline, but it nevertheless differs considerably from the Calc-Alkaline Series in chemical composition and in rock types. Rosenbusch attempts to compare the chemical characteristics of the three series by taking four analyses from each, ranging through acid to basic types; the value of this comparison, however, is reduced by the fact that so few analyses are chosen while each series exhibits so many varieties, and more especially by the fact that the four analyses representing any one series are not of rocks of any one locality, or even of one continent. It is sufficiently evident, however, that the three series coincide at their acid and basic extremes, shown, for example, in that they all pass with decreasing silica into peridotites and pyroxenites. It is interesting to note that Rosenbusch has here made the term "charnockite" of general application, in spite of the fact that Holland emphatically declared[3] that it ought not to be used outside India; if the term had not been so extended, however, a new term would have been necessary for general application to those groups of rocks, now known in many parts of the world, that closely resemble the Charnockite Series of India in all essential respects. Moreover, since the term was extended by Holland himself from the rock-name Charnockite to the name of the whole series, it is only logical to extend it to similar series elsewhere.

The Magnesian Group embodies the greater part of the Charnockite-Anorthosite Series, and includes also the highly magnesian rocks commonly associated with this Series. It is at present uncertain, however, where a distinction may be drawn

[1] C. E. Tilley, "The Granite Gneisses of Southern Eyre Peninsula (South Australia) and their Associated Amphibolites": *Q.J.G.S.*, vol. lxxvii, 1921, p. 75.

[2] *Elemente der Gesteinslehre*, 1910, p. 187.

[3] "The Charnockite Series": *Mem. Geol. Surv. India*, vol. xxviii, 1900, p. 131.

between rocks of the Magnesian Group and the basic members of the Alkaline and Calc-alkaline Series; it is obvious that strong resemblances exist amongst these rocks. The Charnockite-Anorthosite Series and associated rocks, forming the most important members of the Group, are for the most part of pre-Cambrian age, whereas the other series referred to include types that are considerably younger.

A careful comparison of the chemical and mineralogical features of the three series as they are represented in West Africa has been made by Lacroix.[1] He has shown that the rocks of both the Charnockite-Anorthosite Series and the Calc-Alkaline Series are rich in magnesium and also in hypersthene, besides containing variable amounts of the magnesia-pyroxene.

The Spilitic Suite, proposed by Dewey and Flett,[2] is distinguished from both the Alkaline and the Calc-Alkaline Suites mainly by abundance of soda-felspars and by association with special contemporaneous geographical conditions; in the opinion of several later writers,[3] however, the Spilitic Suite is essentially a modification of the Calc-Alkaline Suite. Accordingly, the remarks already made as to the relation of the Alkaline and Calc-Alkaline Series to the Magnesian Group may be applied also to the Spilitic Suite.

Again, Wolff [4] has suggested that certain basalts and basaltic rocks should be grouped together under the term "Arctic Tribe", and he has further proposed to include the Charnockite Series in this group. Washington,[5] however, in a careful discussion of the Charnockite Series of India and a comparison of these rocks with analogous types of other regions, shows that the charnockitic rocks are clearly distinguishable from the ordinary basaltic or gabbroic rocks.

In conclusion, it may be mentioned that the conception of the Magnesian Group of Igneous Rocks is based on evidence that increases with our growing knowledge of the older parts of the earth's crust, and it is accordingly now put forward in the hope that it expresses a principle which may possibly be of some slight assistance in the general problem of the origin and relations of igneous rocks.

[1] "Les Syénites Nepheliniques de l'Archipel de Los": *Nouv. Arch. du Mus. d'Hist. Nat., Paris*, 5me Série, Tome 3, 1911, p. 108.

[2] "Some British Pillow-Lavas and Associated Rocks": Geol. Mag., 1911.

[3] See R. A. Daly, *Igneous Rocks and their Origin*, 1914, p. 340.

[4] F. v. Wolff, *Vulkanismus*, i, 1914, p. 153.

[5] "The Charnockite Series of Igneous Rocks": *Amer. Journ. Sci.*, 1916, p. 323.

Some Points in Petrographic Nomenclature.

By G. W. Tyrrell, A.R.C.Sc., F.G.S., F.R.S.E., Lecturer in Geology, University of Glasgow.

DR. ARTHUR HOLMES has laid all petrographers under a debt of gratitude for his *Nomenclature of Petrology*, which worthily succeeds and replaces Löwinson-Lessing's *Lexique Pétrographique*. It represents an enormous amount of patient labour, and will provide an indispensable instrument of petrographic research. Its perusal has led the writer to consider several points in modern petrographic nomenclature which seem to need further discussion.

There is no need to labour the extreme complexity, unevenness, and confusion of present-day petrological nomenclature. Dr. Holmes illustrates it in his Introduction by compiling a list of no fewer than twenty-two different principles and characters upon which names have been based. This state of affairs is attributed by him to two causes: the natural tendency for the meaning of terms to expand and assume a wider connotation than originally intended; and the lack of a generally accepted classification. The first cause, as is shown by Holmes, really depends on the second; since meanings inevitably expand and wander unless the terms are restrained within the bounds of a sufficiently rigid framework of classification. The question of classification is therefore at the root of our nomenclatorial difficulties; and agreement upon a classification by petrographers, or the enforcement of a classification through the influence of a sufficiently powerful and inspiring teacher, especially in the case of igneous rocks, seems to be a pre-requisite to the successful reform of the nomenclature.

While not wishing to enter upon the extensive and involved subject of classification, it is desirable to remark that it is impossible for petrographers to wait until a genetic scheme of classification is evolved, particularly for igneous rocks. Furthermore, if and when a genetic classification is developed which commands general assent, it is extremely unlikely that it will lend itself to the detailed quantitative treatment that is so necessary for the purposes of petrographical research. In the meantime a grouping of rocks based on empirical characters susceptible to quantitative subdivision is urgently needed. Recent essays at classification have attempted to supply this need, but none have yet won general agreement amongst petrographers. There will be purists who will object that such groupings of rocks are not classifications at all, but indexes. But so long as we have an instrument that will enable us to describe and compare rocks in an exact and detailed manner, we shall be indifferent as to whether it is called a classification, a grouping, or even an index. Genetic classification will come in due time; but it will be broad-based upon the exact data provided by the quantitative instrument.

Considerable outcry has been made in the past by a conservative school of petrographers against the supposed enormous increase in the number of rock names, many of which are regarded by them as unnecessary. Yet, counting the names given in Holmes' glossary, dating up to 1920, we find that only 428 igneous rocks have separate names (excluding compound terms built up with mineral qualifiers, which, however, do not figure in the list). Some of these are nearly or quite obsolete; others are redundant, or cover but a minute portion of the petrographical field, or depend for their value on trivial differences that would not now be recognized as suitable bases for nomenclature. A great many of these names would certainly be discarded upon a critical revision. Probably less than half of the igneous rock names, or say about 200, are used at all frequently or with close definition, and are thus woven into the living texture of petrological science. Similarly there are only 137 sedimentary and 104 metamorphic rock names, which are subject to the same considerations as are made in the case of igneous rocks.

We may draw the conclusion that there are not too many rock names; on the contrary, there are ridiculously few, especially when the subject is compared with sister natural history sciences. There are certainly insufficient names to cover the enormous field of rocks at all adequately, and petrography thus suffers from a deficiency rather than a plethora of names. There are insufficient terms to indicate what are often considerable degrees of difference in rocks. Moreover, the terms in use are unequally distributed over the petrographical field; in common types of rocks a great range of difference may be covered by single names like andesite or basalt, whereas in a single small restricted group, as in some alkalic families, there may be a superabundance of names for closely related and essentially identical types. The terms andesite and basalt, especially, are greatly overworked, a circumstance that results in confusion in several fields of petrological research, notably that of petrographic provinces.

Dr. Holmes notes some of the disadvantages of the prevalent fashion of basing new rock names upon geographical terms. This method certainly brings about some ugly and cacophonous results, many petrographers having apparently not considered the question of euphony in naming their rocks. It is natural to prefer riebeckite-aegirine-granite to *fasitibikite*; and all petrographers will approve of the condemnation of such monstrosities as *kauaiite*, *auabohitsite*, and others that could be mentioned. Dr. Holmes seems to prefer the alternative method of prefixing a locality name to well-known petrographical terms, on the model of Markle basalt, Ponza trachyte, etc.; or using compound mineralogical prefixes in the same way. He states that names such as hornblende-biotite-granite are self-explanatory; but they are only so if the content of the rock term itself is well understood. The term *granite* in itself is no more self-explanatory than *bandaite* or *marloesite*;

and if the term *bandaite*, for example, is as well defined and understood as granite, the compound orthoclase-olivine-bandaite becomes as self-explanatory as hornblende-biotite-granite.

It is impossible to discuss the reform of petrographical nomenclature, in igneous rocks at any rate, apart from the consideration of the need for quantitative classification, preferably upon a mineralogical basis. Only when this is established will it be possible to make a serious attempt to systematize nomenclature. It may then be worth while to consider new prefixes and suffixes to be added to the roots at present in use, or whether it would be preferable to make a clean sweep, and begin *de novo* with a brand-new scheme of nomenclature. Only in relation to an exact scheme of classification will it be possible to discuss what amount of difference from already described and named types would justify a new name being given. In the absence of an accepted framework of classification, petrographers are justified in coining new names for rocks which, in their judgment, differ sufficiently from already recognized types for a new name to be of value; and when they consider the ascription of a divergent rock to a known class as a restriction of the usefulness of the latter by unduly widening its meaning.

A perusal of Dr. Holmes' glossary suggests many interesting points of nomenclature of which it will only be possible to discuss a few in this paper. It may be remarked in passing that Dr. Holmes' definitions are admirably concise and well expressed. He has rightly chosen to record the customary and current meanings of the terms, and has abstained from critical comment, which could only have been satisfactorily conducted from the standpoint of classification, and would have overstepped the intention of the book.

The abundance of andesites and basalts, and their importance in petrogenetic and distributional studies, renders their exact definition and difference a question of considerable magnitude. Dr. Holmes states (p. 32) that the modern primary distinction between andesite and basalt does not depend on the absence or presence of olivine, or on the relative proportions of felsic to mafic minerals (though each of these criteria have been applied in the past), but on the composition of the plagioclase. As bearing on this statement it is noteworthy that in the last comprehensive work on igneous rock classification[1], the main distinction between andesite and basalt is based on the proportions of felsic to mafic minerals, the true basalts (p. 197) having equal or nearly equal amounts of each, the andesites being preponderantly felsic. It is recognized that the felspar in andesites is *usually* andesine or oligoclase, and that in basalts labradorite or even more calcic varieties; nevertheless, labradorite-andesites are described as well as oligoclase-basalts. When containing olivine labradorite-andesites have often been described as

[1] Iddings, *Igneous Rocks*, vol. ii, 1913.

olivine-basalts; when free from olivine they have been designated either as basalt, felspar-basalt (Fr. labradorite), or, as frequently, andesite.

The reasonableness of Iddings' position is demonstrated by a study of the quantitative mineral composition of average andesite and average basalt. Professor R. A. Daly has computed the average andesite and basalt from the analyses of rocks named as such in Osann's lists.[1] These averages are set out for comparison in Table I, 1, 2.

TABLE I.

Chemical Composition of Average Andesite and Basalts.

	1.	2.	3.
SiO_2	59·59	49·06	47·20
TiO_2	·77	1·36	2·44
Al_2O_3	17·31	15·70	14·93
Fe_2O_3	3·33	5·38	4·11
FeO	3·13	6·37	8·23
MnO	·18	·31	·25
MgO	2·75	6·17	6·92
CaO	5·80	8·95	10·02
Na_2O	3·58	3·11	2·71
K_2O	2·04	1·52	·84
H_2O	1·26	1·62	2·13
P_2O_5	·26	·45	·33
	100·00	100·00	100·11

1.—Daly's average andesite, *tonalose*, II.4.'3.4. *Igneous Rocks and their Origin*, 1914, p. 26. Anal. No. 46.

2.—Daly's average basalt, *andose-camptonose*, (II) III.5.3.'4. Op. cit., p. 27, Anal. No. 53.

3.—Average plateau-basalt, *auvergnose*, III.5.(3) 4.4'. Computed from thirty-seven analyses of plateau-basalts from the Brito-Arctic region (Siberia, North Russia, Franz Josef Land, Spitsbergen, Greenland, Jan Mayen, Iceland, Faroe Islands, and the Inner Hebrides); the Columbia and Snake River plains, Western United States; and the Carboniferous Clyde plateau, Midland Valley of Scotland. Analyses obtained from H. S. Washington's "Analyses of Igneous Rocks, 1883–1913", Prof. Paper 99, *U.S.G.S.*, 1917; A. Holmes, "The Basaltic Rocks of the Arctic Region", *Mineral. Mag.*, xviii, 1918, 180–223; and H. G. Backlund, "On the Eastern Part of the Arctic Basalt Plateau," *Acta Academiae Aboensis, Math. et Phys.*, i, 1920, 1–53.

These computations are not ideal, for there can hardly be any doubt but that each of them covers too wide a range of rocks. The andesite average contains rocks which to-day would be designated as dacite, latite, perhaps even trachyte. The basalt average no doubt contains rocks which would nowadays be called andesite; but this, perhaps, is partly compensated for by the inclusion of rocks such as limburgite, trachydolerite, basanite, etc., which diverge in various directions from true basalt. Daly's average andesite is thus probably more silicic and alkalic than the real average andesite; while the average basalt is probably defective in the same direction, although to a less extent than the andesite. However, these

[1] *Igneous Rocks and their Origin*, 1914, pp. 26–7.

analyses, when calculated into the norms, which closely correspond to the modes in essentials, illustrate well the fundamental differences of andesite and basalt. Andesite is a dofelsic type, basalt mafelsic, more than five-eighths of the total mineral content in andesite belonging to the felsic group of minerals, and less than five-eighths in basalts. This fact is illustrated by the norms (tabulated in Table II), the average andesite falling into *tonalose*, II.4.3.4. and the average basalt into camptonose III.5.3.4.

TABLE II.

NORMS OF AVERAGE ANDESITE AND BASALT.

		1.	2.	3.
S	Quartz	14·70	—	—
	Orthoclase	11·68	8·90	5·00
	Albite	30·39	26·20	23·06
	Anorthite	25·31	24·46	25·85
F	Diopside	1·77	13·87	17·70
	Hypersthene	8·04	11·86	10·17
	Olivine	—	1·87	4·85
	Magnetite	4·87	7·89	6·03
	Ilmenite	1·52	2·58	4·56
	Apatite	·51	1·01	·67
	Ratio S/F	4·89	1·53	1·22

The norms are arranged in the same order as the analyses in Table I.

No petrographer has any hesitation in classing the dense, heavy, generally olivine-bearing rocks of the great basalt floods (Brito-Arctic region, Deccan, Western America, etc.) with the true basalts; the types about which there is doubt as to their position, labradorite-andesite, bandaite, andesitic basalt, basaltic andesite, olivine-andesite, olivine-free basalt, felspar-basalt, and the like, are mostly to be found in andesitic provinces. Daly's average basalt includes rocks of both types, and is therefore both more felsic, and the felspar more alkalic, than in true basalts. An average computed from the analyses of basalts belonging to the plateau-basalt regions of the world should be distinctly more basic than Daly's average basalt. This was found to be the case on computing the average of thirty-seven plateau-basalts (Table I, 3) from the Brito-Arctic region, the Columbia and Snake River plains of Western America, and the Carboniferous Clyde plateau of the Midland Valley of Scotland. This average falls into the subrang *auvergnose*, III, 5.4.4–5, and its norm is stated for comparison in Table II, 3.

The general increase in basicity (maficity) from andesite to plateau-basalt is well shown by the diminution of the S/F ratio. The border-line between andesite and basalt should be at the ratio S/F 1·67, if the distinction be made on the basis of the ratio of felsic to mafic constituents. In this connexion it should be pointed out that the norm ratio is always higher than the mode ratio, since the method of computing the norm always ensures the

maximum possible amount of salic constituents. In considering the norms another point of interest bearing on the question of classification is that the normative plagioclase remains practically of the same chemical composition throughout the series, the basaltic felspar being only slightly more calcic than andesitic. While it is not urged that the average modal plagioclases of andesites and basalts are of nearly the same composition, the above fact certainly seems to tell against the distinction between andesite and basalt being based on the nature of the felspar only.

Another interesting question concerns the nomenclature of the so-called hypabyssal rocks. Some authorities regard the minor intrusions or hypabyssal rocks as a classificatory division co-ordinate in importance with the plutonic and the volcanic. Others regard them merely as textural modifications of plutonic types consequent upon slightly different cooling histories. It is probably best to treat these rocks as textural modifications both of plutonic and volcanic types, having chemical and mineral compositions corresponding with one or the other. This implies that plutonic and volcanic rocks do not exactly correspond in chemical and mineral characters; that is, the average andesite, for example, has not the same chemical and mineral composition as the average diorite, or the average basalt that of the average gabbro. This has been demonstrated by Daly in his studies of average igneous rock types.[1] The exact differences need not now be dwelt upon. It follows, however, that some hypabyssal rocks, porphyries for example, would best be described as andesite-porphyries, others as diorite-porphyries, and so on. It is probably the subconscious and implicit recognition of this fact that has led to many terms in hypabyssal rock nomenclature gradually acquiring a textural significance, while still retaining a specific meaning. Aplite and pegmatite are outstanding examples of this extension of meaning. They have well understood specific meanings; when used alone they mean respectively granite-aplite and granite-pegmatite. But syenite-aplite, gabbro-pegmatite, and like terms, are equally well understood, in which the terms aplite and pegmatite have a textural meaning. It may well be questioned whether such an extension of meaning is not the inevitable end of all hypabyssal rock terms if these types be regarded, not as co-ordinate in classificatory value with plutonic and volcanic rocks, but merely as textural satellites of either group. The textural signification of aplite, pegmatite, and porphyry, may apply to the whole chemical and mineralogical range of igneous rocks. Aplites and pegmatites, however, are always satellitic to plutonic types; porphyries may be attached to either plutonic or volcanic types. Other hypabyssal terms, if used with textural significations, may, however, not apply to the whole range of igneous rocks. *Felsitic*, *keratophyric*, and *orthophyric* apply only toward the "acid" end of the igneous series; *bostonitic* and *tinguaitic*

[1] *Igneous Rocks and their Origin*, 1914, Table II, p. 19.

apply to intermediate felspathic and felspathoidal types; and *doleritic* applies to the more "basic" types of igneous rocks corresponding in general chemical composition with gabbros and basalts.

With the above use of *porphyry* the term *porphyrite* ceases to have any significance. It has been used to indicate porphyritic hypabyssal rocks of andesitic or dioritic composition. The term has been so variously used that it would be better to drop it altogether, and to use diorite- or andesite-porphyry, in which the prefixes give the mineral composition, and "porphyry" the characteristic texture.

The terms *dolerite* and *doleritic* should always carry the connotation of ophitic texture. In some cases it may be difficult to distinguish between a coarse-grained basalt and a dolerite (Holmes, p. 83); but a coarse-grained basalt with its usual intergranular texture is quite different from the rock that it is customary to call dolerite, at least in Scotland. Moreover, ophitic texture is rare in the true effusive basalts, whereas it is very common in the intrusive dolerites even when these rocks are of similar grain-size to coarse basalts, or of even finer grain. Used by itself the term *dolerite* may be understood to carry the mineralogical implication of basic plagioclase, augite, and iron-ore, the rock corresponding in chemical and mineral composition to either gabbro or basalt, and as being characterized by ophitic texture. The average basalt is more "basic" (mafic) than the average gabbro; and corresponding variations are to be found in the dolerites, some of which are of gabbroid, others of basaltic composition. This use of the term would allow it to be also used, with a textural significance, for the hypabyssal equivalents of other "basic" plutonic and volcanic rocks. There is a real need for terms such as teschenite-dolerite, essexite-dolerite, and the like, for rock types quite common in Scotland and elsewhere, which can be given no more suitable names.

In connexion with *teschenite* it should be recognized that this term connotes more than "an alkali-rich variety of analcite-dolerite characterized by the presence of idiomorphic purple augite or aegirine-augite, and generally containing soda-amphiboles such as barkevikite" (Holmes, p. 224). Many of the rocks are quite as coarse as the average gabbro, and are free from doleritic characters such as ophitic texture. The term teschenite should denote analcite-gabbro, just as theralite denotes nepheline-gabbro. The rocks of the smaller intrusions, and marginal modifications of the larger and coarser masses do, however, possess doleritic characters; in which case they are more correctly referred to as teschenite-dolerite or doleritic teschenite. The treatment of teschenite as analcite-gabbro has been tacitly adopted by Dr. A. Harker in the latest edition of his *Petrology for Students* (1919), where the rock is dealt with in the chapter devoted to gabbros, whereas in the previous edition it was described under the heading of dolerite. By

Iddings teschenite is treated as a plutonic rock, but is regarded as an analcitic variety of theralite, in which the analcite "may be altered nepheline".[1] This view is a survival from the period in which the analcite in this and in other rocks was thought to be of secondary origin. Nepheline does occur in some teschenites, and is often altered; but it does not alter into analcite. Analcite has been shown to be a primary constituent of teschenite, and many other analcitic igneous rocks; but owing to its aqueous constitution, and the consequent mobility and chemical activity of its solutions or magma, it is an extremely efficient agent of paulopost alteration in previously formed mineral constituents, with the result that analcite itself has been regarded as secondary. In other words the analcite is not due to the alteration of the other minerals, but the alteration is due to the analcite. If analcite be recognized as a primary mineral constituent in teschenite, this rock is as valid a rock species as theralite, and deserves equal recognition in a system.

We have no space in which to discuss the nomenclature of sedimentary and metamorphic rocks at any length. One point that struck the writer in reading Dr. Holmes' *Nomenclature of Petrology* was that the term *psammitic* was treated as exactly synonymous with *arenaceous*, also *pelitic* with *argillaceous* (p. 35), and *rudaceous* with *psephitic* (p. 202). It would appear consonant with current use, however, to restrict the terms of Latin derivation to sedimentary, and those of Greek derivation to metamorphic rocks. We do not speak of arenaceous gneiss but of psammitic gneiss; pelitic schist, in like manner, is regarded as a more felicitous term than argillaceous schist; whereas the adjective *psephitic* usefully describes the metamorphic rocks derived from the metamorphism of conglomerates, etc. The term *arenaceous* conveys (at least to the writer) a suggestion of past, present, or potential looseness of grain, whereas the corresponding less well-known Greek term does not carry this suggestion. Similarly *argillaceous* conveys a suggestion of softness, plasticity, and extremely fine grain, which is not so directly conveyed by *pelitic* except perhaps to Greek scholars. Hence it is suggested that the terms *psammitic* and *pelitic* might usefully be restricted to the hard metamorphic rocks which have been changed beyond the limits implied by the corresponding Latin terms.

Grabau's term *rudaceous*, applied to coarse detritus such as gravel, shingle, talus, and their compacted representatives, completes the trilogy of Latin adjectives for the principal gradings of sedimentary rocks. The term *psephitic* is not quite synonymous with rudaceous as it also conveys the suggestion of rounded pebbles. This sense is also seen in the use of the term *psephicity* by Mackie to indicate degrees of roundness in sand grains. But as during metamorphism angular fragments tend to become more or less rounded, the term *psephitic* will apply with considerable degree of exactitude to those

[1] *Igneous Rocks*, vol. ii, 1913, p. 248.

types formed by the metamorphism of rudaceous sedimentary rocks. The above suggested use of the terms *psephitic*, *psammitic*, and *pelitic*, has been adopted in many recent memoirs of the Geological Survey of the United Kingdom, especially those dealing with the gneisses and schists of the northern, north-western, and Grampian Highlands.

On a Mammoth Molar from North Woodchester, near Stroud.

By Frank Raw, B.Sc., F.G.S.

(PLATE X.)

THE tooth, of which a photograph (half-size) is reproduced, was found during Easter, 1916, by the late Mr. W. Harrison, of Selly Oak, Birmingham, who kindly lent it to the writer. Though similar finds are fairly common, this tooth by its form is of rather special interest, and so the writer thinks merits description.

According to the note written down at the time it was received from Mr. Harrison, it was found "at North Woodchester, at the base of the hill that rises to Selsley Hill". This village is about $1\frac{3}{4}$ miles S.S.W. of Stroud, Gloucestershire, on the west side of the valley that runs here behind the edge of the Cotteswolds, of which Selsley Hill forms a part. North Woodchester lies along the road that runs west from the bottom of this valley (perhaps 150 feet O.D.), and rises to Selsley Hill (689 feet). The range in height of the village is from 200 feet O.D. to 300 feet O.D., and from the description of the site by Mrs. Harrison the writer judges the altitude of the find to be about 300 feet O.D.

The tooth was found in a gravel pit, the gravel consisting largely of Oolitic and Liassic debris. *Terebratula globata*, fragments of *Belemnites*, and *Ammonites serpentinus* were recognized by the writer among the material collected from it by Mr. Harrison. As North Woodchester, according to the Geological Map, lies on Upper Lias, it may be concluded that the deposit of gravel lies on this formation, whence was derived *Ammonites serpentinus* and probably the *Belemnites*. Selsley Hill is of Inferior Oolite, which also forms the high ground to the east and covers a large area to the north.

Mammoth remains seem fairly common in these gravels near Stroud. W. C. Lucy in 1869 [1] records the occurrence of remains of the mammoth, woolly rhinoceros, reindeer, and bison (*Bos primigenius*) in Gannicox Pit, Stroud, as well as land and freshwater snails from lenticles of clay interstratified with the gravel. Mr. Edwin Witchell [2] who had discovered these fossil shells, describes the gravels and their fossil contents, mentioning "fine tusks of the mammoth

[1] W. C. Lucy, "The gravels of the Severn, Avon, and Evenlode, and their extension over the Cottesawold Hills": *Proc. Cottes. Nat. F.C.*, vol. v, 1869.

[2] E. Witchell, *The Geology of Stroud*. Also *Stroud Nat. Hist. and Phil. Soc.*, 1876–8. *Proc. Cottes. Nat. F.C.*, vol. viii, 1883.

and teeth of the woolly rhinoceros and reindeer". He states that "there is an absence of marine or estuarine shells in these gravels", and that "it is therefore probable that the whole of these gravels are of fresh-water origin, and were the drifts and breakers of a lake which once occupied the valley of the Severn". The writer knows of no facts militating against this conclusion. Mr. L. Richardson,[1] in a report of a visit of the Cotteswold Club to the Gannicox and Cainscross gravel pits near Stroud, in the course of a useful summary of what was known of the fossil contents of the gravels, gives a list of thirteen species of land and freshwater shells obtained by Witchell from clayey seams in the gravels, not one of which is a marine species.

The assemblage of mammalia is of glacial character and points to a time near that of the "Würm" glaciation, the last of the major glaciations established by Penck and Brückner in the Alps, and coinciding with the formation of the "Newer Drift" of the North European plain. It was there that the mammoth was most numerous, though its remains are fairly common in deposits of the earlier "Riss" glaciation. Mammoth remains are also recorded from a considerable number of places in and around the Cotteswolds. It is generally agreed that there was no glaciation of the Cotteswolds, which were too high to be overflowed, but not high enough to nourish glaciers of their own, and the writer imagines that herds of mammoths roamed over the area, while the Welsh mountains, perhaps at that time higher relatively than now, owing to an uptilt of the country to the west, shed extensive glaciers across the estuary of the Severn, and by damming back the waters formed a lake, to the fluctuating levels of which the Cotteswold streams built deltas, but to quote Mr. Richardson,[2] "more work is necessary" (and the writer has done none) "before any suggestion of value can be made."

Description of the Tooth.

The tooth measures 8 inches in length, by $4\frac{1}{2}$ inches deep, by $2\frac{3}{4}$ inches wide, the photograph being half natural size. In shape it closely resembles a yacht, the worn surface of the tooth corresponding to the deck of the ship; but the front of the yacht is seen in the posterior end of the tooth and vice versa.

The lateral aspect is about equally divided between the complexly folded broad crown and the narrower "keel", the depth of crown and keel being about equal to one another in the different parts of the length. The worn surface being oblique, one lateral aspect (the outer) has less crown than the other.

The superior aspect is entirely occupied with the grinding surface, which, though nearly flat, is obliquely concave. This measures $7\frac{1}{4}$ by $2\frac{3}{4}$ inches. All the tooth folds or "plates" that remain are worn, the keel being only 1 inch below the posterior border,

[1] L. Richardson, *Proc. Cottes. Nat. F.C.*, vol. xviii, 1914, pt. iii, p. 205.

[2] L. Richardson, "Excursion to Stroud": *Proc. Cottes. Nat. F.C.*, 1914, p. 205.

types formed by the metamorphism of rudaceous sedimentary rocks. The above suggested use of the terms *psephitic*, *psammitic*, and *pelitic*, has been adopted in many recent memoirs of the Geological Survey of the United Kingdom, especially those dealing with the gneisses and schists of the northern, north-western, and Grampian Highlands.

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(PLATE X.)

THE tooth, of which a photograph (half-size) is reproduced, was found during Easter, 1916, by the late Mr. W. Harrison, of Selly Oak, Birmingham, who kindly lent it to the writer. Though similar finds are fairly common, this tooth by its form is of rather special interest, and so the writer thinks merits description.

According to the note written down at the time it was received from Mr. Harrison, it was found "at North Woodchester, at the base of the hill that rises to Selsley Hill". This village is about $1\frac{3}{4}$ miles S.S.W. of Stroud, Gloucestershire, on the west side of the valley that runs here behind the edge of the Cotteswolds, of which Selsley Hill forms a part. North Woodchester lies along the road that runs west from the bottom of this valley (perhaps 150 feet O.D.), and rises to Selsley Hill (689 feet). The range in height of the village is from 200 feet O.D. to 300 feet O.D., and from the description of the site by Mrs. Harrison the writer judges the altitude of the find to be about 300 feet O.D.

The tooth was found in a gravel pit, the gravel consisting largely of Oolitic and Liassic debris. *Terebratula globata*, fragments of *Belemnites*, and *Ammonites serpentinus* were recognized by the writer among the material collected from it by Mr. Harrison. As North Woodchester, according to the Geological Map, lies on Upper Lias, it may be concluded that the deposit of gravel lies on this formation, whence was derived *Ammonites serpentinus* and probably the *Belemnites*. Selsley Hill is of Inferior Oolite, which also forms the high ground to the east and covers a large area to the north.

Mammoth remains seem fairly common in these gravels near Stroud. W. C. Lucy in 1869 [1] records the occurrence of remains of the mammoth, woolly rhinoceros, reindeer, and bison (*Bos primigenius*) in Gannicox Pit, Stroud, as well as land and freshwater snails from lenticles of clay interstratified with the gravel. Mr. Edwin Witchell [2] who had discovered these fossil shells, describes the gravels and their fossil contents, mentioning "fine tusks of the mammoth

[1] W. C. Lucy, "The gravels of the Severn, Avon, and Evenlode, and their extension over the Cotteswold Hills": *Proc. Cottes. Nat. F.C.*, vol. v, 1869.

[2] E. Witchell, *The Geology of Stroud*. Also *Stroud Nat. Hist. and Phil. Soc.*, 1876-8. *Proc. Cottes. Nat. F.C.*, vol. viii, 1883.

and teeth of the woolly rhinoceros and reindeer". He states that "there is an absence of marine or estuarine shells in these gravels", and that "it is therefore probable that the whole of these gravels are of fresh-water origin, and were the drifts and breakers of a lake which once occupied the valley of the Severn". The writer knows of no facts militating against this conclusion. Mr. L. Richardson,[1] in a report of a visit of the Cotteswold Club to the Gannicox and Cainscross gravel pits near Stroud, in the course of a useful summary of what was known of the fossil contents of the gravels, gives a list of thirteen species of land and freshwater shells obtained by Witchell from clayey seams in the gravels, not one of which is a marine species.

The assemblage of mammalia is of glacial character and points to a time near that of the "Würm" glaciation, the last of the major glaciations established by Penck and Brückner in the Alps, and coinciding with the formation of the "Newer Drift" of the North European plain. It was there that the mammoth was most numerous, though its remains are fairly common in deposits of the earlier "Riss" glaciation. Mammoth remains are also recorded from a considerable number of places in and around the Cotteswolds. It is generally agreed that there was no glaciation of the Cotteswolds, which were too high to be overflowed, but not high enough to nourish glaciers of their own, and the writer imagines that herds of mammoths roamed over the area, while the Welsh mountains, perhaps at that time higher relatively than now, owing to an uptilt of the country to the west, shed extensive glaciers across the estuary of the Severn, and by damming back the waters formed a lake, to the fluctuating levels of which the Cotteswold streams built deltas, but to quote Mr. Richardson,[2] "more work is necessary" (and the writer has done none) "before any suggestion of value can be made."

Description of the Tooth.

The tooth measures 8 inches in length, by $4\frac{1}{2}$ inches deep, by $2\frac{3}{4}$ inches wide, the photograph being half natural size. In shape it closely resembles a yacht, the worn surface of the tooth corresponding to the deck of the ship; but the front of the yacht is seen in the posterior end of the tooth and vice versa.

The lateral aspect is about equally divided between the complexly folded broad crown and the narrower "keel", the depth of crown and keel being about equal to one another in the different parts of the length. The worn surface being oblique, one lateral aspect (the outer) has less crown than the other.

The superior aspect is entirely occupied with the grinding surface, which, though nearly flat, is obliquely concave. This measures $7\frac{1}{4}$ by $2\frac{3}{4}$ inches. All the tooth folds or "plates" that remain are worn, the keel being only 1 inch below the posterior border,

[1] L. Richardson, *Proc. Cottes. Nat. F.C.*, vol. xviii, 1914, pt. iii, p. 205.

[2] L. Richardson, "Excursion to Stroud": *Proc. Cottes. Nat. F.C.*, 1914, p. 205.

while in front the grinding surface cuts across the base of the crown, exhibiting the bottom of an enamel infold. Twelve plates are evidenced together with a talon behind, but it is impossible to say how many have been ground away entirely in front.

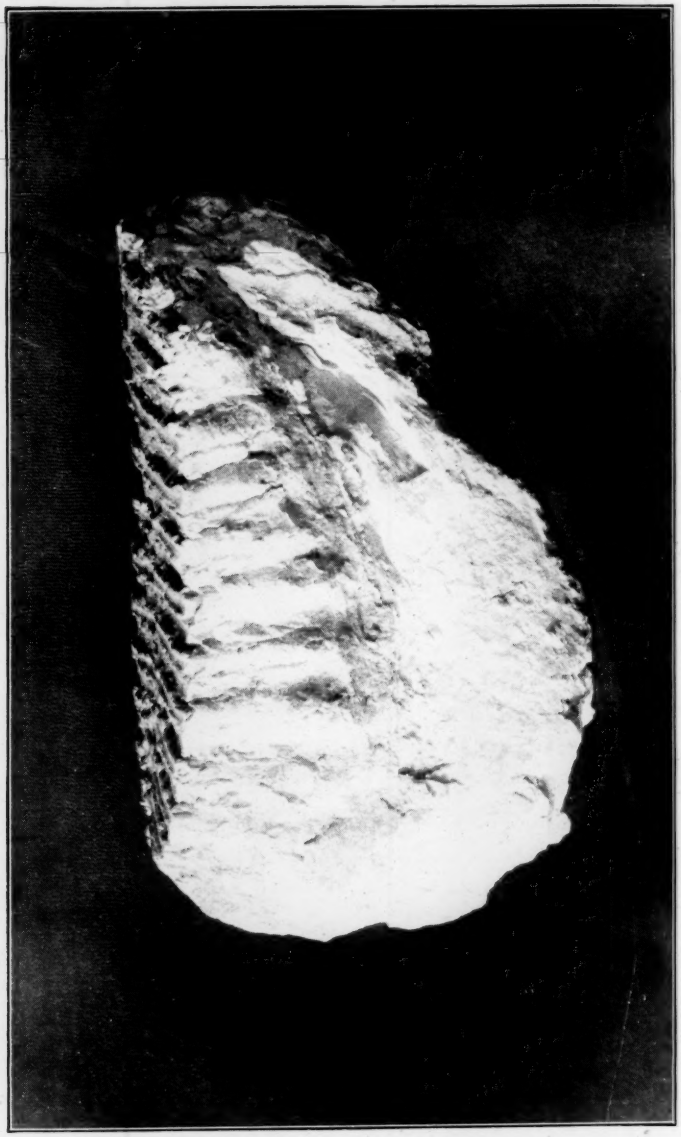
The curved shape of the base of the crown and its relative shallowness indicate that this is a *lower* molar, and since when looked at from above the plates run obliquely forward to the left, it is seen to belong to the *right* side of the mandible.

Posteriorly the crown narrows like the prow of a ship to a relatively fine edge, and thus gives *no* suggestion of pressure being exerted through a tooth following it in the jaw. This would indicate that it is the last tooth or third true molar. Its characters thus indicate an *ultimate right lower molar*.

For specific determination of such teeth reliance is placed on the form and spacing of the "plates" and the thickness and form of the enamel layers as seen in section on the grinding surface. In the Woodchester specimen the plates are closely spaced and the dentine and cement are in parallel bands and almost exactly equal to one another, but the posterior plates are drawn forward and constricted near their middle. The closeness of the plates is indicated by the length of tooth for a definite number of plates. There are ten complete folds in 5·75 to 6 inches or eight full size in 4·6 inches. The enamel is about ·06 in. thick, is crimped, and especially throughout the posterior half of the tooth forms compressed outfolds on the plates. These characters taken all together indicate *Elephas primigenius* or the *Mammoth*, though each of these characters could without doubt be matched among teeth ascribed to *Elephas antiquus*. According to Dr. Adams [1] the number of plates, not counting the talon or heel at each end in the last molars of the mammoth ranges from 18 or 19 to 27, the width from 2 to 4½ inches, the closeness of the plates from eight plates in 5 in. to the same number in 3·1 in. In our tooth the measures given above of width (2¾ in.) and closeness of plates (eight in 4·6 in.), fall well within this range. But as already noted detrition here is very far advanced, the remaining portion of the crown varying from 1 in. deep behind, through 2 in. at its deepest, to 0 in. in front and so the number of plates is quite unknown. And as the commonest number of plates in these teeth is probably 22 or 23, the plates at the anterior end which are worn right away to the base are the middle ones of the entire tooth. Thus the superior surface probably measured originally 14 in. or 15 in. by 2¾ in., while we may take the original depth of the crown as probably 4 in. or 4½ in. The animal was thus in advanced old age, and had worn away all but one-sixth or one-eighth of the volume of the crown of its last teeth.

Moreover, the occurrence of a continuous keel below the crown in place of a number of fangs seems to be characteristic of the last part

[1] A. Leith Adams, "British Fossil Elephants": *Palæontographical Society*, 1877–81, p. 125.



MOLAR OF MAMMOTH, SOUTH WOODCHESTER, STROUD. ½ SIZE. *Photo: F. Bone.*

Facing p. 505.

of the last tooth and part of the arrangement for pushing it up into a working position in the absence of pressure from behind. Mr. Adams (loc. cit., p. 121), describing a much detrited last lower molar in the Woodwardian Museum, says: "The fangs had become consolidated into a ridge like the keel of a vessel"—an exactly similar condition to that here displayed. This character may thus be taken as confirming the conclusion otherwise arrived at that this is an ultimate molar. For a microscopic examination of the substance of the keel the writer is indebted to Mr. W. Courtney Lyne, who identifies it as dentine, which normally composes the fangs.

Compared with last lower molars of the mammoth described by Mr. Adams (loc. cit.), and with the fragments in the Birmingham University Geological Museum, this is rather a narrow tooth, but the measures of several narrower are given in the work referred to. On the other hand, judging by what remains, it would, when complete, be fully as long as the complete molars there described, but these from their very completeness are probably for the most part smaller than the average. It is, indeed, by no means as large in any dimension as they often attain.

The tooth is in a good state of preservation, the grinding surface, though much cracked, preserving the original relief and a fair degree of polish on the enamel. But at the sides of the crown the cement has in places fallen away as has also dentine from the keel. It exhibits no effects of water-wear and so cannot have been carried by water far from the mandible and the skull. There is every probability, therefore, of more mammoth remains having been entombed in the neighbouring gravel.

The tooth is in the possession of Mr. Harrison's widow, to whom the writer is deeply indebted for an extended loan of the specimen and for information regarding the position of the find.

EXPLANATION OF PLATE X.

Photograph of ultimate right lower Molar of Mammoth found at North Woodchester, near Stroud, by the late Mr. W. Harrison, of Selly Oak, Birmingham, Easter, 1916. Photo—half natural size.

The Primary Zones of Cornish Lodes

By E. H. Davison, B.Sc., F.G.S.

DURING the last two and a half years I have been engaged in the study of the Cornish Veinstones in the field and in the laboratory by microscopic and other methods, and have come to the following conclusions:—

That, as recognized by many observers, the primary minerals of Cornish lodes occur in zones which change their character in depth; thus copper minerals give place to cassiterite on passing down the lode and chlorite gives place to tourmaline.

From observations on over 150 lodes in more than 100 different mines, taken on the spot or abstracted from old records, in and

around the Carn Menellis granite mass, from Camborne and Redruth on the north to Falmouth and Helston on the south, it appears that the boundaries of the various zones can be determined within reasonable limits. I felt some hesitation at trusting to old records of depth which were sometimes measured on the underlie of the lode and sometimes vertically, but on determining the average depth below surface at which predominant copper gives place to copper with tin, from old and recent records, in the neighbouring parishes of Redruth and Camborne taken separately (the two areas having a similar geological character). I found that the two results differed by less than 15 fathoms, which shows that the estimates were sufficiently accurate to justify the conclusions drawn.

The general character of the zoning as regards tin and copper has been described by MacAlister,[1] but wolfram and arsenic are also to be considered, as they are important lode constituents. The general occurrence of the minerals is as follows:—

1. A zone situated some distance above the granite surface in the clay slate and often extending beyond the metamorphic aureole in which the metals silver, lead, and zinc are predominant. These metals arrived later than the tin or copper and often filled fissures belonging to a later period of earth movement, but they are also occasionally found in the uppermost parts of the tin-copper lodes, and this was probably still more often the case before the lodes were so extensively planed down by denudation.

2. A zone in which copper is the predominant metal comes next below the silver-lead zone. The copper zone passes downwards into the next zone at a depth which depends on the level of the granite surface.

In the neighbourhood of ridges or of "cupolas" on the granite surface the place of copper is usually taken by wolfram, and there is then a wolfram zone just above or just inside the surface of the granite mass.

3. A zone characterized by the occurrence of both tin and copper in fair proportions. In the proximity of "cupolas", or ridges, this zone becomes in many instances a tin-wolfram zone.

4. A zone in which cassiterite is the predominant metallic mineral.

In no mine has the lower limit of this tin zone been actually reached, but evidence obtained in the mines sunk most deeply in the granite seems to indicate that there is a limit to its extension downwards. If the cassiterite does not actually die out, its grain tends to become so fine as to render profitable exploitation very difficult.

In the following notes on the various zones the general characters of the veinstones have been kept in view throughout; local exceptions occur, but only in a few instances.

[1] *Geological Survey Memoir*, Sheet 352, Camborne and Falmouth, 1906.

The Silver-Lead Zone.

The number of instances in which tin- or copper-bearing lodes pass upwards into lodes carrying lead and silver is too small to admit of any generalization. Silver and lead occurred with tin and copper in the Engine Lode, South Tresavean, silver with arsenic in the South Entral Lode, Dolcoath, and horn silver in the lode at North Dolcoath. Most of the lead-silver lodes have a north and south direction, and are of distinctly later date than the tin-copper lodes.

The Copper Zone.

This zone is characterized by the predominance of copper minerals with mispickel as a frequently associated mineral. The copper occurs mainly as chalcopyrite, which seems to be the only original sulphide, the others present, such as bornite, erubescite, cuprite, native copper, and the oxidized compounds having been formed by its secondary alteration. Pyrite and some of the mispickel seem also to be of secondary origin.

Fig. 1.—Sketch section to show relation of zones to granite surface.

The chief gangue minerals are quartz, chlorite, fluorspar, and muscovite; tourmaline is not usually an important component, but occurs locally in one or two districts.

The copper zone is in nearly every case restricted to the clay slate; its lower limit in the Camborne-Redruth district lies at an average depth of 100 fathoms, with a maximum of about 200 fathoms. As it is traced northwards away from the Carn Menellis granite mass, the base of the zone falls steadily (Fig. 1).

The position of the zone in other districts can be seen from the following table:—

District.	*Depth of Base of Copper Zone in fathoms.*		*Position of area, relative to granite.*
	Average.	*Maximum.*	
Camborne and Redruth	100	200	On flank of granite mass.
Gwennap	150	plus 300	Away from granite mass.
Wendron	No Copper Zone.		Heart of granite mass.
Crowan	50		Flank of granite mass.
Gwinear	150	200	Away from granite mass but in area of contact altered slate.
St. Day	60		Flank of granite mass.

The close connexion between the predominance of copper and the granite is shown by instances of lodes passing from slate to granite into slate again, the copper always being predominant in the slate and the tin in the granite.

The Wolfram Zone.

As mentioned above, the place of copper is sometimes taken by wolfram, which occupies a similar relative position in the lode. It is probably not accidental that all the wolfram-producing lodes are found in the neighbourhood of ridges or minor domes ("cupolas") of the granite. In such position the wolfram may be found either in the clay slate, as at Castle-an-Dinas and Killifreth, or just inside the granite, as at Hemerdon and Kit Hill. It may also occur in lodes passing from the slate into the granite, as in the case at Tin Croft Mine, Roger's Lode, East Pool Mine, etc. The lodes are of coarser texture than usual, and sometimes show a pegmatite-like structure, the chief minerals being quartz, chlorite, mispickel, wolfram, and cassiterite; tourmaline is not usually present in large quantities, fluorspar is often present, and molybdenite, stannine, and pyrite are occasional constituents. The wolfram content decreases and the cassiterite increases as the lode is followed from the slate into the granite either in depth or horizontally.

The Copper-Tin Zone.

In most cases the copper zone of a lode passes downwards into a zone in which the lode carries both copper and tin in fair proportions. This zone is perhaps more correctly described as a passage zone from the zone of predominant copper to that of predominant tin, but it is often so clearly marked and has produced so much ore in many mines, that its classification as a separate zone is perhaps justified.

In the various districts the position of the zone is as follows:—

District.	*Depth of Base of Cu Sn zones in Fathoms.*		*Position of Area.*
	Average.	*Maximum.*	
Camborne and Redruth	180	300	On flank of granite mass.
Gwennap . . .	—	—	Away from granite mass.
Wendron . . .	50	100	Heart of granite mass.
Crowan . . .	150	—	Flank of granite mass.
Gwinear . . .	200	—	In area of contact altered slate away from granite.
St. Day . . .	150	—	Flank of granite mass.

The composition of the lode-stuff is similar to that of the copper-zone, but mispickel is more common, and tourmaline is present in greater proportion. The veinstone generally appears under the microscope as well-crystallized, with quartz, chlorite, mica, tourmaline in well-formed blue and brown prisms, chalcopyrite,

mispickel, and cassiterite in large, well-formed crystals. The chalcopyrite and mispickel are seen to have crystallized after the cassiterite, which is often included in them. This type of veinstone is often a bright green colour in the hand specimen, and with a vughy texture; it is locally termed "peach". The number of lodes which pass downwards from a zone with predominant wolfram is small, as few wolfram lodes have been worked to any depth. The facts show, however, that wolfram dies out and cassiterite increases as the lode is followed into the granite and there is possibly a similar passage zone to that of the copper-tin lodes.

The Tin Zone.

In all the lodes the tendency is for the lode to become predominantly tin-bearing in depth. There is also a decided change in the character of the veinstones. The chlorite, so common a constituent in the upper zones, diminishes or disappears, and the type of veinstone locally termed "capel" is the usual one. This is a fine-grained blue veinstone composed of quartz crowded with microscopic needles of blue tourmaline, and often brecciated, the fragments consisting of capel containing fragments of cassiterite, and clear quartz, the cement being quartz, coarser tourmaline, and cassiterite which is more coarsely crystallized and of a paler colour than that in the capel.

There are only a few mines which have been worked to any great depth in the granite, and in consequence the facts on which conclusions might be based are scanty. There seems, however, to be a distinct indication that there is a limit in depth to the tin zone. In many instances the cassiterite not only decreases in amount, but also becomes af a decidedly finer grain, thus rendering the lodestuff less amenable to concentration by gravitational methods.

In reference to the fine grain of the cassiterite in some veinstones, both at moderate and considerable depths in the granite, I would refer to my paper read before the Royal Geological Society of Cornwall,[1] in which cassiterite is described as occurring in the form of minute inclusions in quartz, the grains being less than one micro-millimetre in diameter.

The extent of the zones described above varies very greatly at different points round the granite mass, and this variation has been attributed[2] to the variation in slope of the granite surface below the slate. Recent development of the mines has produced fresh evidence of the fact that the Carn Menellis mass slopes very gradually to the north below the clay-slate (Figs. 2, 3, and 4). The occurrence of a large inclusion of granite in the quartz-porphyry ("elvan") dyke at Bridge, near Portreath, suggests that even so

[1] "On the Mode of Occurrence of Cassiterite in Cornish Veinstones, etc.": *Proc. Roy. Geol. Soc. Corn.*, 1919.

[2] MacAlister, *Geol. Surv. Mem.* Sheet 352, Camborne and Falmouth, 1906.

far to the north as that the granite is at no great distance below the surface, and there is every probability that the copper and tin zones occur at workable depths over a large area to the north of the present mines in the Camborne-Redruth district.

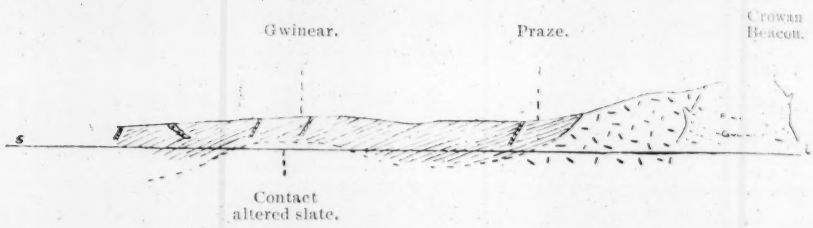


FIG. 2.—Sketch section from Crowan Beacon to Gwinear.

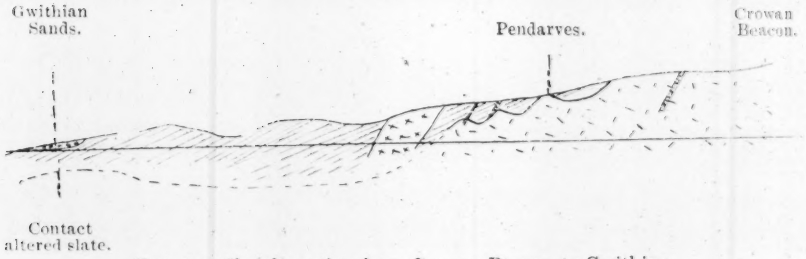


FIG. 3.—Sketch section from Crowan Beacon to Gwithian.

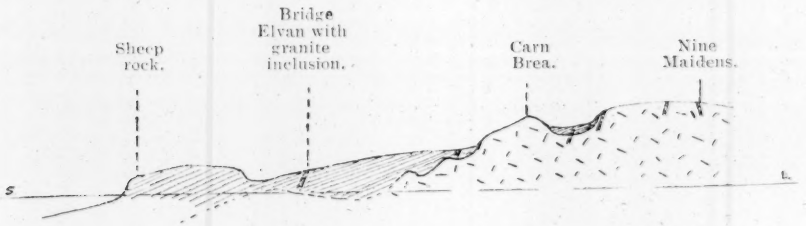


FIG. 4.—Sketch section from Nine Maidens to Portreath.

In addition to the vertical zones of the lodes described above, there is a variation in the lode contents along the strike. A lode is not usually of uniform value throughout its length, but the metallic minerals occur in "shoots" or "courses" which alternate along the lode with areas of low-grade ore of little or no economic value. These shoots are not usually vertical, but run diagonally down the lode and their exact relationship to their surroundings remains to be determined. It seems probable that they are due to variation in the country rock, and in the nature of the fissure, and I am at present engaged in the collection of data concerning them.

The Order of Arrival of the Minerals.

The detailed microscopic study of the veinstones has shown that the order of arrival of the minerals is not always the same. As a general rule the order, as shown by the relations of the constituent minerals, is :—

1. Quartz, mica, tourmaline, topaz, cassiterite, wolfram, stannine, and molybdenite.
2. Quartz, chlorite, fluor, chalcopyrite, mispickel, pyrite, and blende.
3. Lead and silver ores.
4. Secondary minerals such as other sulphides of copper, scheelite, carbonates, etc.

Wolfram is often earlier than cassiterite, and the latter is usually before tourmaline. Chalcopyrite is often before mispickel, and pyrite is usually later than both.

Veinstones of Unusual Characters.

In many instances the close relationship between igneous intrusion and lode formation is easily seen. The veins at Hemerdon,[1] Kit Hill, St. Michael's Mount, and Cligga Head are, as a rule, veins of greisen or pegmatite in the granite.[2] In other cases veinstones occur which have all the characters of pegmatites so far as texture and simultaneous crystallization are concerned. Such is the vein seen in the stope between the 148 and 160 levels, New Cook's Section, South Crofty, which shows large porphyritic crystals of wolfram, interlocked with coarsely crystalline quartz, mispickel, stannine, and chlorite, the minerals having crystallized at or about the same time. In Tin Croft Mine, again, there occurs a veinstone composed of quartz, altered felspar, chlorite, wolfram, and mispickel, with smaller proportions of cassiterite and fluorspar, in which the quartz wolfram and felspar penetrate one another.

Another occurrence of interest in this connexion is that of the pegmatite near the bottom of Dolcoath New Shaft, in which cassiterite occurred associated with garnet.

The association of cassiterite with acid intrusives is also shown by its frequent occurrence as a constituent of quartz-porphyry dykes ("elvans"). The occurrence at Parbola Mine is well-known, and microscopic examination has shown it to occur in many of the quartz-porphyry dykes of the Carn Menellis area.[3]

This constant connexion between the occurrence of the cassiterite with the products of the residual magma confirms the generally accepted idea that, by whatever means it was carried to and deposited in the lodes, the source of the metal was the granite magma.

[1] "On the Characters of some Cornish Veinstones": *Proc. Cornish Inst. of Engineers*, 1920.

[2] "On the Geology of St. Michael's Mount": *Proc. Roy. Geol. Soc. Corn.*, 1920.

[3] "On the Mode of Occurrence of Cassiterite, etc.": *Proc. Roy. Geol. Soc., Corn.*, 1919.

Evidence bearing on the Deposition of Cassiterite.

The structure of an alluvial pebble of cassiterite found in the Nanpusker Valley throws some light on the manner in which the mineral was deposited. The pebble consists of a roughly hemispherical nodule of cassiterite about half an inch in diameter with white quartz attached; through this quartz rays of cassiterite needles run radiately from the main mass. Microscopic exmination shows that the cassiterite nodule is crystalline dark brown in colour and beautifully zoned. The rays consist of two kinds. Nearest to the nodule there are bunches of dark brown cassiterite needles, and further away there is a zone of yellow prisms of cassiterite with good crystal outlines, while outside these the quartz is crowded with small needles and skeleton crystals. The quartz is seen to be a mosaic of small irregularly shaped grains, which are in optical continuity around the ends of the cassiterite crystals and needles. The structure shows that the cassiterite either crystallized contemporaneously with the quartz or that crystallization took place in a silica jelly sufficiently viscous to hold the needles in position.

In conclusion, I must express my thanks to Mr. Harvey Kitto for collecting information with regard to Killifreth Mine, to Tehidy Minerals Company, Limited, for permission to inspect their plans and sections, and to the managers of the various mines visited for giving me valuable information and every facility for carrying out the work.

Platinum-bearing Rocks in the Lizard District.

By G. McPherson, jun., Stud.I.M.M., and T. Lamb, Stud.I.M.M.

SOME remarks made at a meeting of the Cornish Institute of Engineers by Dr. R. H. Rastall directed attention to the possibility of platinum being found in the Lizard. In a paper upon "Ore Deposits of Igneous Origin", Dr. Rastall pointed out that in the Lizard the local characteristics were favourable to the presence of platinum, although no definite information of its occurrence had been reported. Much interest was aroused locally by these remarks, and the writers resolved to investigate the alluvials derived from the altered ultrabasic igneous rocks of the Lizard Group.

The main rock features of the Peninsula may be shortly indicated as follows. Against the Ordovician and Devonian schists of Cornwall lies the Lizard Group of greatly altered igneous and sedimentary rocks of the Basement Complex, separated from the schists by the Lizard fault and a much brecciated belt which traverses the Peninsula from east to west. The Lizard Group may be briefly described as consisting of mica- and hornblende-schists successively intruded by ultrabasic, basic, and acid bosses and dykes, all much altered by regional metamorphism. Minor intrusions are common, and frequently along the borders of the larger masses mixed rocks

are found, apparently derived by interaction between intrusive and country rock.

The ultrabasic bosses, which Dr. Rastall indicated as the possible sources of platinum, cover the centre and south-west of the Peninsula, and also appear as small intrusions in other parts. They consist of massive serpentine, and three main varieties have been previously outlined namely: Dunite-serpentine to the north, bastite-serpentine in the centre and south-east, and tremolite-serpentine to the west. The constant association of platinum with ultrabasic centres of dunite has been elsewhere noted, and it was considered that search around this mass of serpentine should prove most profitable. The dunite serpentine is a light-coloured rock, greyish-green, whitish or bluish in colour, very streaky, and containing octahedra and grains of magnetite and chromite. Its mass is on the highest central part of the Lizard plateau, and from the watershed streams arise which flow north to the Helford river, and east, south, or west to the sea. The alluvial bodies are very narrow and shallow, and contain little gravel, being mainly composed of clayey silt, and therefore not very favourable to the presence of mineral placers. No mineral deposits are known within this serpentine, which is exposed over an area of about $2\frac{1}{2}$ square miles.

The first tests were made by panning the surface of the alluvials with a small pan to recover any minerals of high specific gravity which might be present. The concentrates obtained were examined and found to consist of magnetite, a little chromite, and particles of dunite-serpentine, but no visible platinum. However, it was decided to assay the concentrates, and after fusion with litharge and fluxes, and cupellation of the resulting lead buttons, two minute beads of platinum were obtained weighing respectively 4 mg. and ·35 mg. These were tested and definitely proved to be platinum. They indicate values of approximately 10 mg. Pt. per cubic ft. of silt. One of these beads was unfortunately mislaid, but the other remains in the custody of Mr. E. H. Davison, Lecturer in Geology at the School of Mines, Camborne.

As these values had been obtained from the surface silt of the alluvials, and as there was a strong probability of increased values being found near bedrock, it was decided to carry on further research. A prospecting licence was obtained and a pit sunk in one of the alluvials, near Tregadjack Farm, samples being taken at various depths and at bedrock. The results obtained were disappointing, from the economic point of view, as the alluvial proved to be fine silt down to bedrock, and there was practically no concentration of gravel or sand. A greater quantity of heavy concentrate per cubic foot was obtained near bedrock, but on this being examined it was found to be exactly similar to the previous ones, and contained no visible platinum. Samples from the stream beds were also obtained which, on panning, yielded similar concentrates.

The bedrock concentrate was handed over to Mr. E. H. Davison, who offered to assay it. He obtained a bead of platinum of ·048 mg., thus indicating a value of approximately ·024 mg. per cubit foot. This small value would suggest that the concentration of platinum is greater on surface than near bedrock, being due very probably to the fact that the dunite-serpentine has only been exposed by denudation for a short time, and thus no platinum placers have been formed. It was noted, while panning the silt, that several pebbles remained in the bottom of the pan with the heavy sands. These pebbles were always of one variety, a light green rock with a small proportion of metallic mineral finely interlaminated. It is believed by the writers that the fusion assay might reveal that the platinum is contained in this variety of dunite serpentine, but much further research is required to elucidate this point and others, such as whether the platinum exists in a minutely-divided free state or whether it is intimately associated with magnetite or chromite, as appears very probable from the very small amounts of platinum found in the assay.

There still remains a very small chance of an economic deposit being located, as there may be economic values of platinum in the laminated green serpentine, and judging by the amount of this rock found in the alluvials there must be a large body of it existing in the mass from which the streams flow.

Further research into these platinum-bearing rocks became impossible, owing to the writers leaving Cornwall, but there is still plenty of work waiting any enterprising geological student who cares to spend some leisure time in examining the Lizard alluvials and serpentines with a view to making clearer the facts of the above noted interesting occurrence of platinum.

REVIEWS.

THE GEOLOGY OF ANGLESEY. By EDWARD GREENLY. Memoirs of H.M. Geological Survey. Two volumes, 980 pages, 60 plates, 17 folding plates, 346 text-figures. 1920. Price 3 guineas.
GEOLOGICAL MAP OF ANGLESEY, scale 1 in. to mile. Colour-printed. Price 2*s.* 6*d.*

THE appearance of this map and memoir is an event of first-rate importance in British geology, justly comparable with the publication of the North-West Highlands memoir, of world-wide renown. The two have, indeed, much in common; both result from the application of detailed large-scale mapping to regions prominently composed of ancient crystalline rocks, both formulate tectonic conceptions of great boldness and grandeur, and if the area of Anglesey be small, it may fairly be claimed to be more complex, less well-exposed, and to include a much greater variety of later formations. On the personal side, however, the present production stands apart from almost all its great predecessors in that it is substantially the work of one man, who single-handed and at his own expense has devoted more than twenty years of his life to its accomplishment.

The memoir is divided into five parts. Part I comprises an introduction, a history of previous research, and a very complete bibliography. Both in spirit and method the author's treatment of the work of his numerous predecessors leaves nothing to be desired, his admiration of their achievements is patent, and he concerns himself less with the restatement of dead controversies than with the recognition of each worker's contribution to our knowledge of the island. Part II, which occupies the remaining 352 pages of the first volume, is devoted to the study of the "Mona Complex", this being the term bestowed upon the series of ancient metamorphic rocks which occupy some two-thirds of the surface. Part III, occupying most of the second volume, deals with the later formations, which include representatives of nearly every Palæozoic system, an interesting set of Tertiary dykes, and widespread glacial deposits. Part IV is devoted to economics, and in Part V are gathered together a number of additional studies of the nature of postscripts, many representing important developments in the author's views on the Mona Complex during the progress of publication. Appendices give particulars and statistics of maps, specimens, and plates, while in a final supplement the author presents a connected account of his views on the metamorphism of the Mona Complex.

In Parts II and III the treatment is naturally stratigraphical, and has the advantage of a uniform plan. For each system a general account is first given. This commences, after a short introduction,

with a description of the petrology, followed by an account of the palæontology after which the succession is established and a general view of the development of the formation throughout the island is given, and concludes with such matters as thickness, relations to other formations, and an attempt at a restoration of the physiography of the period. A separate chapter on the details of local development is provided for those who wish to study the formation in the field, and where necessary another chapter deals with the Tectonics. In the treatment of the Mona Complex the order is slightly varied, and many sections of the general account are replaced by whole chapters.

For the majority of geologists this account of the Mona Complex will be the outstanding feature of the work, and there can be no doubt that the decipherment of the succession and structure of this complicated and often highly crystalline tract is Mr. Greenly's crowning achievement. Work of such nature demands that petrological investigation go hand in hand with field work, and its successful issue must be ascribed to the author's capacity to carry out both lines of research. Out of a complex in which some seventy rock types are distinguished, including representatives of all the commoner types of sediments, spilites and associated jaspers, felsites, tuffs, and plutonic rocks ranging from serpentines to granites, he is able to establish the existence of a number of rock groups. These groups occur in several isolated regions, and in varying states of metamorphism, some even developing important changes of facies, but by the application of stratigraphical principles based on precise mapping, these difficulties have been overcome and a definite order of succession made out. Furthermore, the discovery of pebbles from one group in the conglomerates of another has given definite evidence of the chronological order in which this succession must be read. Thus we attain the conception of an original bedded succession of six principal subdivisions resting upon an ancient floor of yet older foliated rocks of which it is conjectured that certain gneisses form the only visible representatives. Into this bedded succession has been intruded a varied suite of plutonic intrusions, and the whole subjected to powerful regional metamorphism. Three special peculiarities of the Mona Complex are emphasized, its high sodium and titanium contents, which show themselves in the great predominance of albite among the felspars and ilmenite among the iron ores, and its persistent green colour due to the abundance of anamorphic chlorite.

That this remote epoch was not without organic life is indicated by the discovery of annelid pipes and castings, while the jaspers are suspected to be altered radiolarian rocks.

The succession once established, the author proceeds to demonstrate his views on the tectonics of the Complex in a chapter of singular interest. The key to the interpretation is found in Holy Isle, where the effects of pitch and of two great normal faults combine

to bring in higher and higher tectonic horizons. Anomalies are at once apparent, which can only be reconciled by postulating very extensive inversions, and thus recumbent folding is established as the dominant structure of the Complex. Two great master-folds with complementary thrusts or slides are recognized from the evidence in Holy Isle, while upon other evidence, admittedly less complete, a third fold is also postulated. The impulse is throughout from the north-west, and amplitudes of the order of 60 miles are suggested. Superposed upon these primary structures are secondary and tertiary folds and thrusts of extreme complexity, with amplitudes which vary from thousands of feet to fractions of an inch, and to the stresses causing this later folding the author attributes the widespread regional anamorphism of the Complex. The apparently capricious variation in intensity of the metamorphism is shown to be dependent on the position of the beds in the tectonic succession, in accordance with the principle that anamorphism is a function of depth. To this, however, there is one striking exception, which has caused the author much concern before arriving at an explanation which he regards as satisfactory.

On the important question of the age of the Complex he is on firmer ground. He proves beyond the possibility of doubt that its regional metamorphism was complete, and that denudation had cut deeply into its most crystalline members before the basal Ordovician conglomerates were laid down. This in itself goes far to establish a pre-Cambrian age, but Mr. Greenly has gone further and obtained direct evidence from the mainland, where he has recognized pebbles from many horizons of the Complex in the basal Cambrian conglomerates and Harlech Grits. Thus, both the materials and metamorphism of the Mona Complex and—if the author's views upon tectonics be accepted—its recumbent folding are proved to be of pre-Cambrian age. The importance of this result to workers in other British areas of crystalline schists needs no demonstration.

With some understanding of the fascination which these ancient schists have exercised over the minds of so many great geologists, we turn almost reluctantly to the later formations. But the author's energies show no signs of flagging, and he devotes to their consideration 421 pages full of interesting facts and brilliant generalizations.

He commences with the study of a few small outliers of unmetamorphosed rocks intermediate in age between the Complex and the Ordovician. Of these certain volcanic rocks are correlated with the volcanic group of Bangor, while some sedimentary patches are regarded as the last relics of a former widespread sheet of Cambrian deposits, soon afterwards swept away by sub-Ordovician denudation.

Passing to the Ordovician, which after the Complex is the most widespread formation in the island, we learn that there seems to be

a complete succession, in which, notwithstanding the nearness of Snowdonia, no trace of volcanic activity is found. Save for the basal conglomerates and grits, the facies is graptolitic throughout, there being a complete passage from an Arenig and Llanvirn of typical Welsh character into a Glenkiln and Hartfell of striking similarity to the Scottish succession, which extends even to a development of the "Barren Mudstone" facies. There is no sign of overlap in the formation until the northern coast is reached, when all the zones below the Glenkiln suddenly disappear, and we are confronted with a distinct northern facies; this phenomenon, so long a source of misconception, becomes in the author's hands the key to the interpretation of the post-Silurian earth movements.

Silurian rocks, once probably widespread, are now preserved only in the deep infold of Parys Mountain, which has yielded a rich Valentian graptolite fauna, and is also the seat of remarkable metasomatism. These phenomena, of which the once famous copper ores represent a certain phase, are fully treated in a separate chapter.

Attention is next directed to the great suite of Palæozoic intrusions, whose dykes are so conspicuous upon the map. They are shown to have a wide range in composition, from the well-known "Hornblende-picrites" to felsites, and cogent reasoning establishes their genetic connexion with the post-Silurian earth movements.

As would be expected from its geographical position, these manifestations of the Caledonian crustal disturbances have powerfully affected Anglesey, and their effects are discussed in another absorbing chapter. For the second time we meet with signs of an overwhelming impulse from the north, which becomes increasingly evident as we pass away from the mainland. Folding becomes isoclinal, cleavage develops, minor thrusts appear, and finally we encounter a gigantic rupture curving from coast to coast, along which the whole northern region of Anglesey with its distinct northern facies, both of Mona Complex and of Ordovician, has been driven southwards for a score of miles. This great dislocation has been named the "Carmel Head Thrust Plane", and the shearing, mylonization, and other dynamical phenomena seen along its course strongly recall the lesser thrust planes of the North-West Highlands. The sudden appearance of the northern Ordovician facies now becomes intelligible, and we see that its apparent interstratification with the schists of the Complex is due to the rupturing of infolds produced during the same great disturbances. In an interesting comparison of these movements with those of the Mona Complex, upon which they have been superimposed, the author shows that the phenomena are throughout those of a higher tectonic zone; recumbent folding gives place to fracture, widespread inversion is absent, and foliation and anamorphism are replaced by mineral changes of a katamorphic nature.

Of the Upper Palæozoic formations the Lower Old Red Sand-

stone has a small development of typical character, and does not appear ever to have had a wide distribution in the island; after its accumulation occurred a final feeble renewal of the southward folding impulse.

With the Carboniferous we encounter once more a widespread formation. Its most prominent member is the Carboniferous Limestone, which presents all the normal characters save for an unusual development of transgressive pebbly sandstones at several horizons. All three subdivisions of the *Dibunophyllum* zone can be recognized, and some cherts at the top of the series are referred to the *Posidonomya* zone, but nothing older can be definitely proved, and it is shown that the whole series disappears by gradual overlap in a south-westerly direction. A thin "Millstone Grit", with a peculiar kaolinite matrix, succeeds the limestone, and passes up into Coal Measures, which are only known from mining records, being entirely buried beneath the drifts and alluvium of the Malldraeth Marsh. Fourteen coal seams are known, mostly of small value. These indubitable representatives of the Carboniferous are succeeded unconformably by a series of red sandstones and marls, which have been referred to various geological horizons. The author produces evidence for their reference to the Upper Coal Measures, and correlates them with the well-known Red Measures of the Midland coalfields. Following the deposition of these beds, earth movements again took place, but the horizontal component so conspicuous in the older stresses is now absent, and all the faults are of the "normal" type, one of them being of great magnitude.

The Mesozoic era being unrepresented in Anglesey, though there is reason to believe that several of its formations were once deposited there, the next rocks described are the interesting Tertiary dykes, of which no fewer than thirty have been mapped.

The glaciation, which next claims attention, has left traces everywhere in the form of drifts or ice-worn features. Numerous striæ and trains of erratics show that the island was traversed by ice moving in a south-westerly direction, and the author's evidence confirms the commonly accepted view that this ice formed part of a great ice sheet, which entirely filled the Irish Sea Basin. Even the highest hills of Anglesey were deeply buried and certain overflow notches show that the ice sheet pressed up against the Carnarvonshire mountains to the height of at least 1,700 feet. Two distinct boulder clays can be distinguished on the eastern coast, separated in places by fluvio-glacial gravels which are taken to indicate an important recession of the ice, though the author refuses to commit himself to a more precise opinion as to its magnitude. Great numbers of extra-insular boulders occur in the drifts, and afford an opportunity for some interesting speculations on the submarine geology of the south-eastern part of the Irish Sea.

A final chapter on the development of the present land surface, which includes the consideration of the Pliocene platforms of erosion,

and the author's already published theory of the origin of the Menai Strait brings the stratigraphical portion of the memoir to a close. The contents of the remainder of the second volume have already been outlined.

In the course of this review no mention has yet been made of the assistance received by the author from other workers. All the fossil identifications are the work of specialists, of whom Miss Elles also contributes an essay on the graptolite sub-faunas, and in the field much help has been rendered by the fossil collectors of H.M. Geological Survey; Mr. J. O. Hughes has carried out a large number of rock analyses, and several distinguished petrologists have lent their aid on special points. All this and much other assistance is duly recognized by the author, who is throughout meticulous in his acknowledgment of help received.

The memoir is well illustrated, most of the 346 clear text-figures are from Mr. Greenly's own pen, while of the 60 plates the greater number are reproductions of photographs taken for H.M. Geological Survey, and of the usual excellent quality; a few are less satisfactory and a number of the collotype plates of rock-sections are disappointing. There are also seventeen folding plates, mainly horizontal sections, but including also some coloured reproductions of the original field maps, a welcome innovation which will be of great value to the field geologist and serves to demonstrate the detailed precision of the author's mapping.

Accompanying the memoir is a colour-printed geological map of Anglesey upon the one-inch scale, which possesses certain advantages. Portions of several sheets of the ordinary issue have been combined to form a single sheet covering the whole island and a number of additional place-names mentioned in the text have been inserted. The reduction of the geological boundaries from the six-inch to the one-inch scale seems to have been well done, and the common error of inserting too much detail has been wisely avoided. The colour model, too, has been skilfully prepared and shows the various formations to advantage. But the general appearance of the map, and what is more, its utility to the geologist, suffers greatly from the bad reproduction of the outline. There seems to be an impression at Southampton that in a map of this kind only the colours matter and that the printing of the topographical detail is of secondary importance. Every field geologist knows the contrary. In the present map the colour printing is adequately done, though the tint given to the Ordovician on the map hardly corresponds with that shown on the legend. But the outline plate is bad, the printing of the title "Anglesey" shows this glaringly, all the lines are thick and lacking in sharpness, the contours are invisible, the smaller place-names all but unreadable, while the muddy grey tint which has been used in the printing to conceal these defects hinders the discernment of the topography under its coating of colour and makes it difficult to follow the author's descriptions.

But these defects are no part of Mr. Greenly's work, and it remains to congratulate him upon an absorbing account of a very remarkable achievement. We understand that he has lost no time in transferring his attention to the Carnarvonshire mainland, and we await with eager interest the results of his work in that equally classic area.

T. C. N.

THE APPENDAGES, ANATOMY, AND RELATIONSHIPS OF TRILOBITES. By PERCY E. RAYMOND. Memoirs of the Connecticut Academy of Arts and Sciences. Vol. VII. 1920. 169 pp., 11 plates and portrait, text-figs.

THE researches of the late Profesor C. E. Beecher on the structure of Trilobites are familiar to all palæontologists, and his restorations have been widely copied in textbooks. It is perhaps not generally known that his writings on the subject were all preliminary to an extensive monograph on which he was engaged up to the very day of his death in 1904. The materials for this monograph, as he left them, comprised a large number of specimens carefully developed, and photographs and drawings of these, but no written notes. At the invitation of Professor Schuchert, who succeeded him in the chair of palæontology at Yale, one of Beecher's pupils, Professor Percy E. Raymond, of Harvard, has taken up the unfinished task, and in this volume, dedicated to the memory of his master, gives the results of his study of the material, illustrated largely by fine reproductions of Beecher's own photographs and drawings.

In a foreword by Professor Schuchert some interesting details are given of Beecher's methods of work. The pyritized specimens of *Triarthrus*, from the Utica shale of Rome, New York, which provided the main subjects of investigation, are as a rule less than an inch long, and the cleaning of the minute details of their appendages was a difficult and tedious business. After various chemical methods had been tried without success, it was found best to depend on abrasives (carborundum, emery, and pumice) applied with pieces of rubber. As development went on, the rubbers were reduced in size so as to abrade only minute areas. The beautiful photographs reproduced in this volume were taken by immersing the specimens in liquid Canada balsam and photographing through a cover-glass with a vertical camera.

Although the primary object of this memoir is to give detailed descriptions and figures of Beecher's material, the author has also re-examined most of the known specimens of Trilobites exhibiting the appendages. In particular he has studied the material worked out by Dr. Walcott, whose help in the communication of specimens and photographs is acknowledged, and he discusses at length the various problems connected with the morphology, phylogeny, and bionomics of the group. The monograph, therefore, covers much the same ground as that of Dr. Walcott, reviewed in this Magazine

two years ago (GEOL. MAG., 1919, pp. 359-63), and a comparison of the conclusions reached by the two writers is of particular interest. Their substantial agreement on all the main points of structure is of importance as showing that our knowledge of the Trilobites' appendages rests upon a sure basis. It is only on matters of detail that there is difference of opinion.

The author has been unable to convince himself of the presence of the epipodites and exites described in *Neolenus* and some other genera by Walcott, and he considers that the appendages were in all cases simply biramous. The two branches are connected with a single basal segment produced inwards to form a gnathobase, or, as Raymond prefers to call it, "endobase." Walcott described this basal segment as formed by the fusion of two segments, the coxopodite and basipodite. Raymond regards it as representing the coxopodite alone, the second free segment being the basipodite, and he states that the exopodite articulates with both of these segments. At the point of attachment of each coxopodite with the body is a calcareous process extending "down from the dorsal test just inside the line of the dorsal furrow". These processes are designated "appendifers", and are compared with the entopophyses of *Limulus*.

In his recent monograph Walcott adheres to his interpretation of the sections of *Calymene*, *Ceraurus*, and *Acidaspis* as showing that these genera possessed spirally coiled branchiæ. Raymond discusses at length the evidence for the existence of these remarkable structures, and while admitting the difficulty of interpreting the appearances seen in the sections, he comes to the conclusion that the appendages in these genera did not differ in essential structure from those of other Trilobites in which the limbs are exposed on the surface of the fossils.

On the question of the affinities of the Trilobita, Raymond is in agreement with Walcott in regarding them as most nearly related to the Crustacea. He even includes them within the sub-class, and regards the other groups of Crustacea as derived directly from Trilobites. In taking this view he has, perhaps, hardly allowed due weight to the non-crustacean characters alluded to in the review already quoted (GEOL. MAG., 1919, p. 363). He also considers it possible that all the other groups of Arthropoda may yet be traced back to a Trilobite ancestry, but he is careful to point out the wide gaps that remain to be filled in before this can be done.

Many criticisms might be offered on points of detail. For example, he states that "the exact homology, segment for segment, between the walking legs of the trilobite and those of many of the Malacostraca, even the Decapoda, is a striking instance of retention of primitive characteristics in a specialized group". This exact homology, however, is only obtained by assuming that the exopodite articulates with both the coxopodite and the basipodite, an arrangement not found in any Malacostracan, nor, indeed, in any Crustacean.

If it were verified, this character would be much more important than a mere coincidence in the number of segments.

On one point the student of recent Crustacea will certainly dissent from Professor Raymond's conclusion. As he states, "Since the earliest times there has been a constant temptation to compare the depressed shields of the trilobites with the similar ones of Isopods," and he has succumbed to this temptation so far as to suppose that the Isopods may have been derived directly from Trilobites and independently of the other Malacostraca. It can be stated with some confidence that this view receives no support from what we know of the structure of recent Isopods. If it is ever permissible to draw phylogenetic conclusions from the facts of comparative anatomy, then it is as certain as anything of the sort can well be that the Isopoda have been evolved from a primitive Mysidacean type. The intermediate steps of this descent are indicated not obscurely, although overlain by divergent specializations, in the Cumacea and Tanaidacea. The resemblances in general aspect between certain Trilobites and certain Isopods are very remarkable indeed, but the view that they indicate descent of the one group from the other can only be compared with those fantastic speculations which would derive whales from Ichthyosaurs and bats from Pterodactyls.

Professor Raymond's discussions of the course of evolution within the group of Trilobites, and of their probable habits and mode of life, are especially interesting and suggestive. The whole memoir, however, deserves careful study by all students of fossil and recent Arthropoda. An index would have helped in its use, but this want is to some extent supplied by a full and methodically arranged table of contents. A word of praise is due to the excellent portrait of Professor Beecher which forms the frontispiece.

W. T. Calman.

Special Reports on the Mineral Resources of Great Britain. Memoirs of the Geological Survey.

Vol. XIX: Lead and Zinc Ores in the Carboniferous Rocks of North Wales. By Bernard Smith, M.A. pp. iv + 162, with 3 plates and 25 figures. 1921. Price 5*s*. 6*d*. net.

Vol. XXI: Lead, Silver-lead, and Zinc Ores of Cornwall, Devon, and Somerset. By Henry Dewey. pp. iv + 72, with 4 plates and 14 figures. 1921. Price 2*s*. 6*d*. net.

Vol. XXII: The Lead and Zinc Ores of the Lake District. By T. Eastwood. pp. iv + 56, with 1 plate and 4 figures. 1921. Price 2*s*. net.

ONE of the most difficult and interesting problems still confronting the scientific student of metallogeny is the elucidation of the origin of the ores of lead and zinc that are found in such large quantities in limestone strata of various ages. At one time it was generally believed that the vein-fillings had been deposited from meteoric waters percolating downwards, or by some form of "lateral

secretion". However, it was soon recognized that these theories left the source of the metals unexplained, and the frequent presence of fluorspar in large quantities was also a difficulty. In America many geologists appear still to hold that meteoric waters are the chief agent in the formation of lead-zinc deposits, especially those of the Mississippi valley, but in Europe the tendency is to seek a deep-seated origin, and to refer the genesis of both ores and gangue to the intrusion of igneous magmas. In the case of the lead-zinc veins of Cornwall, lying in slaty rocks and in obvious relation to granite intrusions, this connexion may be regarded as demonstrated. With the ores in the Carboniferous limestone of North Wales and northern England, it is still a matter of speculation.

The metalliferous veins of the Lake District belong to a type in many respects intermediate between the other two. They lie in Ordovician rocks, and their relations to the intrusions are obscure. Many of them carry a fair amount of copper, and the principal gangue mineral is quartz, with subordinate barytes; calcite and dolomite are rather uncommon, while fluorspar is exceedingly rare.

A careful consideration of the facts set forth in these three memoirs should go far towards solving the problem, and we look forward with much interest to the publication of the remaining volumes dealing with ores of lead and zinc. The evidence thus brought together will also be of great value in settling another doubtful point, namely, the age, or perhaps of more importance, the date of the latest phases of the mineralization, which in some instances appears to have continued into post-Triassic times, as shown, among other cases, by the ores in the Dolomitic Conglomerate in the Mendips and the sandstone cemented by galena at Alderley Edge.

These publications follow exactly the plan of the other volumes of the series: they contain an admirably full and detailed account of all the mines that have been worked in their respective areas, derived partly from personal inspection by the authors, and when such was impossible, from a study of old mine plans and all other available sources of information. Theoretical questions are also briefly discussed, and it is interesting to note that Mr. Bernard Smith obviously inclines towards a magmatic origin for the ores of North Wales. The general impression gained from a perusal of these memoirs is that in spite of present economic conditions there may yet be a future for lead and zinc mining in North Wales, if an extended policy of drainage tunnels can be carried out: much has already been done in this way, and it is devoutly to be hoped that means may be found to carry on and extend this work. In Cornwall, also, it appears probable that the deposits of lead and zinc are by no means exhausted: many of the veins are also extremely rich in silver and may eventually again prove of considerable value. Many of the Lake District veins are not yet fully explored, and there are possibilities for barytes production in the future.

R. H. R.

DESCRIPTION OF ARTHUR'S SEAT VOLCANO. By B. N. PEACH, LL.D., F.R.S. Second Edition. Mem. Geol. Survey of Scotland. pp. 26, with a coloured map and 4 figures. 1921. Price 2*s.* 6*d.* net.

THE first edition of this admirable little memoir was published in 1911. It was a reprint, with slight changes, of the description of the area in the second edition of *The Geology of the Neighbourhood of Edinburgh*. In this second edition Dr. Flett has made a few unimportant alterations in the text, and has added another valuable feature in an appendix describing the characters and classification of the volcanic rocks, according to the modern nomenclature of the Scottish Carboniferous petrographical province.

THE ECONOMIC ASPECTS OF GEOLOGY. By C. K. LEITH. pp. xiii + 457. New York: Henry Holt & Co. 1921.

ONE of the most noteworthy developments of recent years in scientific thought is the general recognition of the fact that all science has an actual or potential economic value. The old lines of demarcation between "pure" and "applied" science are being rapidly swept away, and in no field is this more true than in geology. There is, in point of fact, no such thing as economic geology. What is ordinarily meant by this term is the special application of geological law and theory to problems of present practical moment. During the last seven years this has become abundantly manifest, and an enormous amount of additional interest has been imparted to our science by the realization of its importance as a factor in world-politics and world-industry. There is scarcely a single field of human endeavour in which geology has not some part; mineral resources are, in fact, the foundation of a great part of trade and industry, and their political influence cannot be over-estimated. Another fact now generally recognized is the economic value of purely theoretical investigations. It is unnecessary to labour this point; it must suffice to say that though it is impossible to foresee exactly when a theoretical investigation will become of technical value, it always does so sooner or later. As an example of this we will only mention the bearing of theories of magmatic differentiation on the origin of ore-deposits and their discovery and exploitation on a commercial scale.

Such are the ideas that Professor Leith has set himself to develop in this book and well has he performed his task. It is shown that all branches of geology, even the most apparently abstract, have served or may serve some useful purpose. The first 300 pages are occupied by a systematic account of the occurrence and distribution of mineral deposits, each discussed under two headings, geological and economic. The geological sections are necessarily brief and somewhat sketchy; the economic sections describe the distribution, output, and applications of the minerals and the principal facts

relating to markets, financial and political control and possibilities of future developments.

The latter third of the book is occupied by chapters on exploration and development, conservation of mineral resources, valuation and taxation, the legal and international aspects of mineral resources, geology in war and in relation to engineering, and the training of the economic geologist. All these chapters contain admirable summaries of their subjects, and should be widely read. Perhaps of most interest are those on the national and international aspects of mineral resources. These are, of course, mainly written from the American standpoint, and it is striking to find that the United States, the oldest and greatest democracy, shows the least tendency of any country towards State ownership of minerals. Professor Leith gives some wise words of warning as to the dangers of subjecting industries of such paramount importance to the cumbrous, slow-moving, and unenterprising control of a bureaucracy.

There is much wisdom, also, in his advice as to the training of the economic geologist; he insists as strongly as possible on the necessity for a wide general education and a good grounding in pure science. In fact, his view amounts to this: "Learn the pure science and the economic side will look after itself." That is to say, the applications will be acquired gradually as a result of experience and practice. No man can tell beforehand in what particular subject he will specialize, and it is impossible to study them all in detail in an educational course. Nevertheless, much may be done by devoting special attention to the illustration of theory by examples of technical application, and teachers, by dealing fully with the theory underlying cases that are understood, may pave the way to the elucidation of others, of equal importance, that are still involved in mystery.

R. H. R.

PRODUCTS OF THE EMPIRE. By S. C. CUNNINGHAM, B.A. pp. 299. Oxford, 1921.

THIS little book aims apparently, and not unsuccessfully, at giving a short popular account of the assets of the British Empire in so far as these relate in the first place to food, drink, drugs, and tobacco, and in the second to raw materials and the produce of mines. As the author points out, there never has been a complete survey of all the Empire's resources, but the Royal Commission appointed in 1912 has issued reports on the produce of certain countries, and these have yielded much information of value. The chapters in this book which will be of most interest to the geologist are, naturally, those upon the metals, coal, and petroleum. The metallic produce is summarized in a useful table at the end of the second chapter on this part of the subject, and the sources of supply, both foreign and British, are duly set out; under the latter

head are included also known deposits which are at present entirely or comparatively unworked, as well as those from which the metals are at present obtained. Thus we read that for aluminium the foreign sources of supply are France, Italy, and the United States, the present British source is Ireland, and the British sources of the future are British Guiana, India, and Australia. The various chapters of the book give an interesting assortment of varied information. Thus, in that on coal we find accounts of the derivation of the word, the origin of coal in geological history, the discovery of coal by man, the beginnings of coal mining, the difficulties and dangers of the process, the kinds of coal, the probable duration of the supply, and the reserves of coal in the Empire.

F. H. A. M.

A Catalogue of British Scientific and Technical Books. pp. xviii + 376. British Science Guild, 6 John Street, Adelphi, London, W.C. 2. Price 10*s.* net.

THIS handsome volume, prepared by a Committee of the British Science Guild, is a bibliography of standard works on all departments of science, using the term in its broadest sense. It cannot fail to be of the greatest value to all scientific workers, and is remarkably cheap at the price, as books go now. Mineralogy, geology, and palæontology are treated as separate subjects, and each is subdivided under different headings. The distinction between economic geology and economic mineralogy has evidently proved difficult to carry out in practice, as might have been anticipated, and these two sections would have been better combined into one. Also we should like to see added in a future edition a few more such books as Lindgren's *Mineral Deposits* and Emmons' *Economic Geology*. The literature of oil geology is also very incomplete. On the other hand, the selection of books on what may be called the pure science side is very good, and many standard but out-of-date works are wisely omitted. In this category, however, we do not include Lyell's *Elements*, which we have been unable to find under any heading: this book can never grow old, and should be read by all students.

In this catalogue are given the number of pages, date, name of publisher, and price of each book.

Geological Itineraries in Anglesey. By Edward Greenly, D.Sc. pp. 12. Liverpool, 1921.

THESE itineraries were originally drawn up by Dr. Greenly at the request of Mr. T. A. Jones, secretary of the Liverpool Geological Society, to serve as a guide for leaders of excursions and other geologists visiting Anglesey. They contain precise directions as to how to reach the different localities, with a summary of what